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REGIONAL ANALYSIS OF LOW FLOW CHARACTERISTICS

SOUTHWESTERN AND WEST CENTRAL REGIONS

AUGUST 1995

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PIBS 2555E

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LOW FLOW CHARACTERISTICS
SOUTHWESTERN AND WEST CENTRAL REGIONS

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November, 1991

Report prepared for:

Ontario Ministry of Environment and Energy

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This report was prepared for the Ontario Ministry of Environment and Energy as part of a ministry-funded project. The views and ideas expressed in this report are those of the authors and do not reflect the policies of the Ministry, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

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7173
March 15, 1990

Dr. L. Logan
Coordinator, Hydrology Network
Ministry of the Environment
River Systems Unit
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1 St. Clair Avenue West
Toronto, Ontario
M4V 1K6

Dear Dr. Logan:

Re: Regional Analysis of Low Flow Characteristics

Please find enclosed our final report concerning the above noted study. Your comments and suggestions on the draft report have been incorporated in this version, together with comments made by others (e.g. Technical Transfer Conference).

Overall, the results of the various methods for regionalizing low flows show promise in that the estimating error which has been achieved appears to be as good or better than that reported for other similar investigations in the literature. However, this work has identified two main areas of additional investigation which we believe should be pursued:

a) Detailed Assessment of Trend, Persistence and Randomness
b) Extension of Regionalization to Other Regions

Thank you for the opportunity to have undertaken this most interesting investigation on your behalf.

Yours very truly

CUMMING COCKBURN LIMITED

H. S. Belore, P. Eng.	D. A. Ashfield, P. Eng.
Manager, Water Resources Division	Project Manager

HSB:mb
Encl.

REGIONAL ANALYSIS OF LOW FLOW CHARACTERISTICS

TABLE OF CONTENTS

Page No.

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION 1-1
- 1.1 General 1-1
- 1.2 Study Objectives 1-2

2.0 LITERATURE REVIEW 2-1
- 2.1 General 2-1
- 2.2 Summary of Literature Review 2-15

3.0 DATA BASE 3-1
- 3.1 General 3-1
- 3.2 Low Flow Characteristics 3-1
  - 3.2.1 Data Base 3-1
  - 3.2.2 Extreme Value Analysis 3-2
  - 3.2.3 Flow Duration Analysis 3-4
  - 3.2.4 Maps 3-4
  - 3.2.5 Data Analysis and Screening 3-5
  - 3.2.6 Screening Results 3-6
  - 3.2.7 Summary of Data Analyses and Low Flow Characteristics 3-9
- 3.3 Physiographic and Hydrometeorologic Data 3-11
  - 3.3.1 Criteria 3-11
  - 3.3.2 Parameters 3-12
  - 3.3.3 Summary of Physiographic and Hydrometeorologic Data 3-16

4.0 REGIONALIZATION OF LOW FLOW CHARACTERISTICS 4-1
- 4.1 General 4-1
- 4.2 Regression 4-1
  - 4.2.1 General 4-1

TABLE OF CONTENTS

Page No.

4.2.2 Methodology 4-2
4.2.3 Transformations 4-3
4.2.4 Regional Regression Results 4-5
4.2.5 Sub-regions 4-5
4.2.6 Summary of Regression Analysis 4-7
4.3 Index Method 4-8
4.4 Mapping Proration 4-9
4.5 Mapping Low Flows 4-10
4.6 Summary of Estimation Techniques 4-11
5.0 TESTING REGIONALIZATION METHOD 5-1
5.1 General 5-1
5.2 Testing 5-1
5.3 Sensitivity Analysis 5-3
6.0 CONCLUSIONS AND RECOMMENDATIONS 6-1
6.1 Conclusions 6-1
6.2 Recommendations 6-1

REFERENCES

APPENDICES

APPENDIX A : Statistical Analysis Procedures
B : Test Station Analysis

LIST OF TABLES

		Follows Page No.
TABLE 2.1	Summary of Literature Review	2-16
3.1	Station List for Data Bases	3-1
3.2	Example of Extreme Value Tabular Format	3-3
3.3	Example Summary Table from Flow Duration Analysis	3-4
3.4	Extreme Value Data Series Statistical Screening Summary	3-6
3.5	Stations with Unacceptable Low Flow Data Set	3-6
3.6	Summary of Independent Parameters	3-16
3.7	Simple Statistics of Independent Parameters	3-16
3.8	Correlation Matrix of Independent Parameters	3-16
4.1	Summary of Regression Analysis - Untransformed Variables	4-3
4.2	Summary of Regression Analysis - Common Square Root Transform	4-4
4.3	Correlation Matrix of Dependent and Independent Parameters	4-4
4.4	Summary of Regression Analysis	4-5
4.5a	Summary of Regional Analysis - Lake Huron Region	4-6
4.5b	Summary of Regional Analysis - West Lake Erie	4-6
4.5c	Summary of Regional Analysis - East Lake Erie	4-6
4.6	Area Averaged Low Flows	4-10
5.1	Summary of Test Station Parameters	5-1
5.2	Summary of Sensitivity Analysis	5-3

LIST OF FIGURES

		Follows Page No.
FIGURE 1.1	Study Area Location	1-3
3.1	Low Flow Characteristics of Southwestern and West Central Ontario	(in pocket)
3.2	Low Flow Frequency Analysis	3-4
3.3	Information Key for Low Flow Characteristic Maps	3-5
3.4	BFI Isoline Map	(in pocket)
4.1	Map of Regions from Residual Analysis	4-6)
4.2	$7Q_2$ as a Function of Drainage Area (Three Regions Combined	4-8
4.3	Q_{95} as a Function of Drainage Area (Three Regions Combined	4-8
4.4	Regional Relationship of $7Q_2$ as a Function of Drainage Area	4-8
4.5	Ratios of 3 and 30 Day Durations to 7 Day Duration as a Function of Recurrence Interval	4-8
4.6	Ratio of $7Q_y$ to $7Q_2$ for Various Recurrence Intervals	4-8
4.7	Unit Low Flow Characteristics of Streams in Southwestern and West Central Ontario	(in pocket)
4.8	Map of $7Q_{20}$ Isolines (from BFI Isolines)	(in pocket)
5.1a	Estimated Versus Observed $7Q_{20}$ for Alternative Estimating Methods	5-1
5.1b	Estimated Versus Observed $7Q_{20}$ for Alternative Estimating Methods	5-1
5.2a	Estimated Versus Observed $7Q_{20}$ for Alternative Estimating Methods	5-1
5.2b	Estimated Versus Observed $7Q_{20}$ for Alternative Estimating Methods	5-1

ABSTRACT

REGIONAL ANALYSIS OF LOW FLOW CHARACTERISTICS

The identification of suitable low flow characteristics within a watercourse is most easily accomplished using continuous hydrometric data recorded for the stream. However, this is limited to the availability of suitable long term discharge records at the location of interest. The objective of this investigation is to develop a practically oriented technique for estimating low flow characteristics at ungauged locations.

Initially, a background review was undertaken to confirm the most appropriate statistical techniques. It was confirmed that the Gumbel III extreme value distribution is acceptable for analysis of single station low flow data. However, as an alternative distribution for samples with large negative skewness, it was determined that the Three Parameter Log Normal Distribution should be used.

The background review also confirmed that several previous investigators utilized multiple linear regression techniques to regionalize low flow characteristics. On the basis of the literature review, it was decided to include the following parameters in the development of a physiographic data base for the Southwestern and West Central Regions of Southern Ontario: drainage area (DA), mean annual snowfall (MAS), mean annual precipitation (MAP), mean annual runoff (MAR), area controlled by lakes and swamps (ACLS), Latitude (LAT), Longitude (LONG), 10/85 slope (SLP), stream length (LEN), years of daily data (DYRS), and Base Flow Index (BFI). After preliminary analysis and screening, a data base was developed for a total of 65 watersheds.

Several alternative methods were considered for regionalizing low flow characteristics (i.e. 7Q20 and Q_{95}) including; i) Regressional Analysis; ii) Index Method; iii) mapping proration and iv) mapping isolines. The methods developed were then applied and evaluated for 10 test stations to confirm the usefulness in predicting low flow characteristics for ungauged watersheds.

Regressions utilizing drainage area (DA), base flow index (BFI) and stream length (LEN) as independent parameters were found to provide reasonable estimates of low flow values. The index, or graphical method was also found to give reasonable estimates of low flows. Both these methods provide low flow estimates superior to those obtained solely from area proration to gauged sites.

Some requirements for additional investigations were also identified, including an examination of possible reasons for persistence, trend and non-randomness in the available low flow data set and further extension of the index, mapping and regression estimating methods to other regions in the Province.

1.0 INTRODUCTION

1.1 General

The knowledge of the hydrologic conditions which exist during low flow conditions can be of primary importance for some watercourses. For example, when analysing water quality conditions, the low flow conditions within the watercourse are a major concern to both the landowner and the Ontario Ministry of the Environment. Other uses of low flow information may include the following:

i) In-stream pollutant analyses (point and non-point sources)
ii) Reservoir design (low flow augmentation)
iii) Environmental appraisals
iv) Feasibility of small hydro developments
v) Water supply and evaluation for water taking permits
vi) Base flow/groundwater recharge and/or contamination analysis
vii) Stream fisheries assessments
viii) Analyse effects of changes in watershed on low flows (e.g. deforestation, urbanization)
ix) Agricultural

The identification of low flow characteristics within a watercourse is most easily accomplished using continuous hydrometric data recorded for the stream. However, the effectiveness of this method is limited since a hydrometric recording gauge may not be located in the vicinity of the study site.

Another available source of information pertaining to drought conditions is the "Low Flow Characteristics" maps which were published several years ago (more than 10 years in most cases) by the Ministry of the Environment. These maps were produced for most regions of Ontario and include exceedance and extreme values describing low flow characteristics of gauged watersheds.

However, a significant amount of additional streamflow measurements are now available across the Province. Furthermore, difficulties can arise in transferring this information to ungauged sites, since generalized procedures are not available.

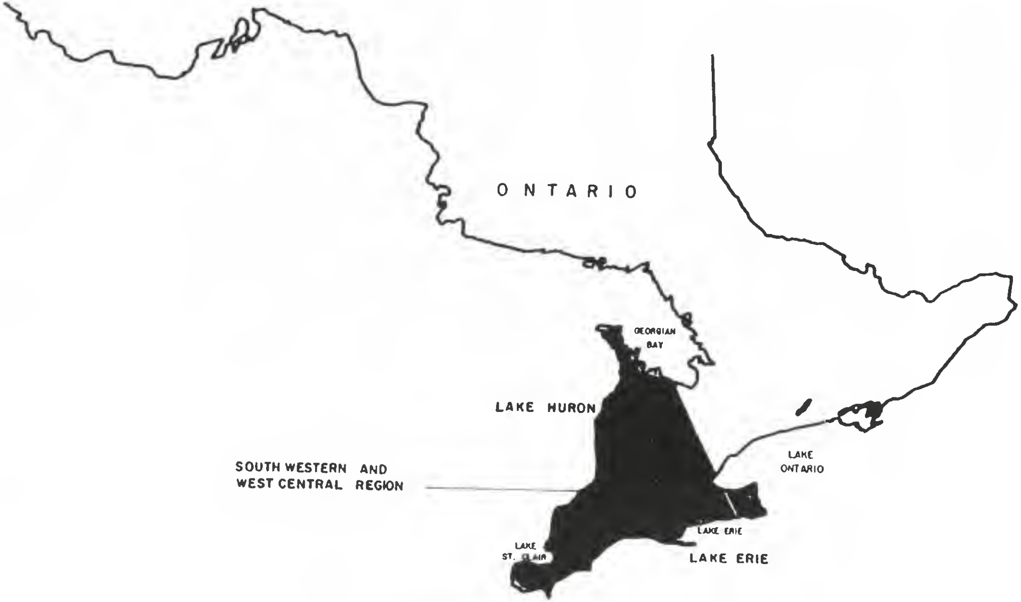
Therefore, this project was conceived to develop the methodology for a regional estimating technique for estimating low flow characteristics at ungauged locations. The test areas selected were the Southwestern and West Central regions of the Province of Ontario (see Figure 1.1).

Regional hydrologic analyses can take several forms and can utilize regression equations, index methods, mapped isolines, etc. However, all of these techniques serve to correlate selected characteristics of an existing hydrometric data base to physiographic and meteorologic parameters which can be measured at both gauged and ungauged watersheds. By utilizing the relationship developed using the gauged watersheds, the required characteristics of streamflow can be estimated for any ungauged watershed within the region.

1.2 Study Objectives

The main objectives are to develop a technique for providing estimates of low flow characteristics for a watercourse based on the physical parameters of the watershed and appropriate meteorological variables. This includes a demonstration application of the technique within the region of development.

The technique could then be further developed and adapted in order to provide estimates of low flows for ungauged watersheds at other locations in the Province.



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N.T.S.

STUDY AREA LOCATION

FIGURE 1.1

2.0 LITERATURE REVIEW

2.1 General

A summary of the relevant results of the review of the various investigations is given in Table 2.1.

The following sections summarize highlights from selected references. The reader should refer to the original reference before attempting to apply specific equations since the units and parameter definitions vary from report to report. The intent here is only to identify important parameters for further consideration in this investigation.

Median Drought Flows at Ungauged Sites in Southern Ontario (Pilon, P. and Condie, R., 1986)

A methodology was suggested and explored for predicting median drought flows at ungauged sites in Southern Ontario. Minimum average flows for durations of 3, 10, 14, 21 and 28 consecutive days were determined each year in the time period June 1 to May 31 for 74 stations in Southern Ontario. A regression equation was developed for predicting the median 10-day low flow using drainage area (DA), mean annual precipitation (MAP), and base flow index (BFI). The precipitation parameter was not significant and, therefore, not included in the equation. The standard error of the low flows was found to be 37% and the equation was in the form:

$$\text{MED}(10) = 0.000075\ \text{DA} + 1.515\ \text{BFI} - 0.356$$

The median 10-day low flow was then used to produce a slope relationship to relate other low flow durations to the MED(10) value. This equation is expressed as:

$$\text{GRADMEN} = 2.632\ \text{MED}(10) + 0.46399$$

where GRADMEN is the slope of the median flow-duration relationship.

A problem noted by the authors is the determination of BFI for ungauged sites. The parameter is used as an index of catchment geology.

Modelling of Low Flow Frequency Distributions and Parameter Estimation (Condie, R. and G. Nix, 1974)

The fit of four theoretical frequency distributions was examined in this study. The Gumbel III distribution was selected as the best fit for extreme value analysis of low flows since it produced 33 acceptable fits out of a possible 38 for the Canadian rivers used in this study. A program FLOINT was written to handle low flow values of zero using a joint/conditional probability function. A discussion of the lower boundary limit being between zero and the lowest recorded flow concluded that the lower boundary can be less than zero since it represents the curve of the line and not the actual flow.

Low Flow Frequency Analysis (Program LOFLOW) (R. Condie and L. Cheng, 1983)

The Gumbel Type III distribution is discussed as well as conceptual problems found from the Condie, Nix 1975 study. It was found that The Gumbel III distribution becomes unstable if the sample has a skewness of less than -1.08. This study concluded that the Gumbel III distribution should be used as the basic method for low flow frequency analysis. As an alternative for samples with large negative skewness, it was suggested that a 3-parameter log normal distribution should be used.

The only criteria of successful fit to the Gumbel III is that the lower boundary parameter should not be larger than the smallest member of the sample. Parameter estimation should proceed in the order of; maximum likelihood, smallest observed drought and by moments. The program LOFLOW was written to analyse samples of low flows taking these concerns into account.

Computation of the Base Flow Index Program (BFINDEX) (P. Swan and R. Condie, 1983)

It was determined that low flows are very dependent on catchment geology, and the Base Flow Index was suggested as a practical technique to provide an index of this parameter. A program was written to calculate a base flow index (BFI) as:

$$\mathrm{BFI} = \frac{\text{runoff under base flow separation line yr.}}{\text{total runoff yr.}}$$

The required data was obtained from records published by the Water Survey of Canada, and averaged BFI values were computed over a period of several years.

The main problem with this technique was determined to be the requirement for discharge measurements. However, it was pointed out that the BFI parameter was found to be fairly stable over botn wet and dry years and, it was, therefore, concluded that it could be estimated from as little as one to two years of gauged record.

Estimates of Low Flows Using Watershed Climatic Parameters (Boyer, P.G. and M. Chang, 1977)

A regional analysis was undertaken for 12 unregulated mountainous watersheds with drainage areas ranging from 164 km^2 to 2345 km^2 (64-916 mi^2 located in West Virginia). There was considerable effort put forward in developing physical watershed parameters for which the evaporative power and drought potential were related logically. Eighteen watershed parameters were tested; drainage area, length of perimeter, mean elevation, mean latitude, maximum relief, relief ratio, basin slope, form factor, main channel slope, main channel length, drainage density, stream frequency, stream order, average angle of tributaries, aspect, length-width ratio, coefficient of compactness and percent of forest cover. Climatic parameters used for analysis were 7-day mean maximum temperature and maximum consecutive days without precipitation for seasonal periods of August to October.

The final model used 3 watershed and 2 climatic parameters, namely; watershed perimeter (CO), the main channel length in miles (LEN), the Watershed Form Factor (WF) (area/maximum watershed length^2). The 7-day 10 year maximum temperature (T_{10}), a function of mean elevation and latitude, and the September 10 year maximum consecutive rainless days (R_{10}), and finally, a function of watershed mean elevation. A prediction equation was developed for the 1:10 year 7-day low flow with a standard error of estimate of about 30% of the observed mean:

$$\ln (7Q_{10}) = 37.0469 + 0.03886(CO) - 0.0401(LEN) - 3.6743(WF) - .5771\ T_{10} + 1.1665\ R_{10}$$

It was concluded that use of climatic parameters which index drought conditions can improve low flow estimates, and that meaningful low-flow estimates can be obtained from climatic and watershed parameters or watershed paramaters alone in a mountainous humid region.

Analysis of Low Stream Flows on Cape Breton Island, Nova Scotia
(Environment Canada, 1978)

This investigation included frequency analysis, using Gumbel III, for 1, 3, 7, 10, 30 day low flow durations based on 11 hydrometric stations with drainage areas ranging from 216 km^2 to 3.6 km^2 (142

mi^2 - 2.4 mi^2). Stations with periods of record from 10 to 59 years were used and those with man-made regulation were deleted.

It was determined that extreme low flow estimates for the short-term hydrometric stations may be high. Seasonal analysis found higher low flows for the summer period. It was suggested that this was due to the climatic and physical location of the stations, and it was noted that evaporative power may also be important. As well, a physiological data base was prepared for a future regression study of 13 parameters relating to the stations examined (see Table 2.1).

Journal of the Hydraulic Division - Characteristics of Low Flows (Task Committee, Surface Water Hydrology, 1980)

This paper summarizes the findings of a U.S. committee regarding the types of low flow information needed, various low flow characteristics and their accuracy, and suggests further analysis and data collection needs. The main topics were discussed according to gauged sites and ungauged sites.

Gauged Site

The most widely-used index of low flow in the U.S. is the 7-day 10-year low flow ($7Q_{10}$). However, it was also found that other durations of from 1-273 days have been based on data records of 15-20 years or more.

Ungauged Sites

It was found that low flow characteristics depend largely on the geology of the basin and on losses from evapotranspiration. For example, the incorporation of basin rock type into regional analysis of low flows increased prediction accuracy for equations developed in Virginia. A regional low flow forecasting model developed (by Wright, 1970) for southeast England relates lowest mean flow for the forecast year to, drainage area, mean annual runoff, geology index, mean summer catchment rainfall in the same year as forecast and, mean winter catchment rainfall (October-March) preceding forecast low flow.

Effects of Man on Low Flows (Riggs, H.C.)

This investigation examined the climatic, geologic and topographic influences on low flow characteristics in view of man's influence. Man-made changes that affect low flows were identified as changes in vegetation, drainage practices, diversions, return flows, groundwater pumping, sewage treatment plants and other effluent discharge.

It was pointed out that the aquifer characteristics are also extremely important to low flows. It was postulated that evapotranspiration and changes to ground cover can likely be related to low flow increases. Urbanization is not a significant factor since pluses (i.e sewer leakage) and minuses (i.e. reduced infiltration) tended to even out. Reservoir regulation usually increases low flows due to minimum outflow requirements. Diversions are highly basin dependent and are difficult to assess.

It was noted that swamps apparently had very small low flows in extreme drought cases. Therefore, it was postulated that changes to swamps (e.g. by infilling, etc.) might not have a significant impact on downstream low flow characteristics. Pumping can have a large effect depending on duration location and basin geology. The three main parameters for low flow are related by; climate providing input and output, geology and topography influencing infiltration to aquifers, and then geologic parameters affecting transport to streams.

Man's influence on precipitation, temperature and irrigation are not likely to effect low flows while changing vegetation cover (evapotranspiration), regulation and diversion are likely to have the most evident effects on low flow.

Hydrology of 7-Day 10 Year Low Flows (Singh, K.P. and J.B. Stahl, 1974)

This paper discusses three pertinent factors in the broad headings of; 1) basin factors; 2) climatic factors, and 3) sociological factors. The main discussion is based upon man's influence and requirement for low flow. It is suggested that basin input to a $7Q_{10}$ low flow study includes information on daily stream flows, soil and stream characteristics, physiographic and hydrologic diversion boundaries, municipal and industrial water use and/or man-made lakes and flow regulation. Again, it is stressed in the conclusions that the magnitude of the drainage area is the most important factor affecting the natural $7Q_{10}$ of hydrologically similar basins.

An Infiltration Index Useful in Estimating Low Flow Characteristics of Drainage Basins (Armbruster, J.T., 1976a)

This investigation concluded that the basin geology was an overriding factor in describing low flow characteristics. Using an SCS soil type based infiltration index, the author of this study was able to improve standard errors in existing prediction equations. The soil index was determined by percentage of basin of soil type A, B, C or D and applying a weighting of 10, 5, 1, 1 respectively and summing for the entire basin. The drainage area and a precipitation index were also found to be significant factors in estimating low flows. The final equation takes the following form:

$$\log 7Q_{10} = -4.658 + 1.068 \log DA + 2.183 \log MAP + .218\ SI$$

Technical Manual for Estimating Low Flow Frequency Characteristics of Streams in the Susquehanna River Basin (Armbruster, J.T., 1976b)

This technical report adopted the infiltration index described in the earlier reference by Armbruster which examined step-by-step procedures for low flow frequency characteristics. In addition, distinctions were made between large and small drainage basins. Large basins have drainage areas of larger than 5,120 km^2 (2,000 mi^2). The parameters used in the regressions were; drainage area, mean annual precipitation, basin surface storage, index of relative infiltration. As well, an index coefficient of the 1-day flow to the 3-day flow of .93 was determined. For large basins, a graph of correction factors for channel length was produced and applied to the regression equation as;

$$\log (7Q_{20}) = -2.029 + 1.052 \log DA + .753 \log (MAP) + CF$$

where CF is the correction factor from the graph.

Combining Estimates of Low Flow Characteristics of Streams in Massachusetts and Rhode Island (Tasker, G.D., 1975)

This report presents a statistical analysis of baseflow measurements and a discussion of the accuracy produced by varying the sample size. It was concluded that empirically estimated values of variance of the estimated $7Q_{10}$ low flow from its true value indicate that more than six or eight baseflow measurements add little to the confidence with which such an estimate is made. As well, the number of baseflow measurements needed to meet a specific accuracy of low flow characteristics can be significantly reduced by considering prior knowledge of the low flow characteristics quantitatively. The formula is:

$$q = \frac{q_r + (Sr^2/Sb^2)\ q_b}{1 + (Sr^2/Sb^2)}$$

where q is logarithm of estimated low flow characteristics
q_r is log Q_r flow estimated by regression of basin parameters
q_b is log Q_b flow estimated by regression of base flow measurements
Sb^2 and Sr^2 are variances in square log units of estimates from true value of low flow characteristics

Probability Distribution of Low Flows (Matalas, N.C., 1963)

This study examined the fit of four probability distributions using both the method of maximum likelihood and moments. The Gumbel and Pearson Type III distributions fitted the data equally well and were more representative of the probability distribution than the 3 Parameter Log Normal or Pearson Type V distributions. Goodness of fit was based on observed minimum flow, the lower limits of the four probability distributions and the relation between skewness and kurtosis of the low flow data. It was recommended that future statistical studies of low flows should use the method of maximum likelihood estimates of parameters rather than moment estimates.

Drought Flows and Receiving Water Assessment (Logan, L., 1986)

This study examined low flows in an environmental context with respect to waste water and failures to satisfy water quality requirements. Low flow design estimates for Ontario Central - Southwest were reported to be:

	Central ($m^3/s/km^2$)		Southwest ($m^3/s/km^2$)		
$7Q_{20}$	1.0	-	0.8	)	
$7Q_{10}$	1.1	-	0.9	)	±.3 $m^3/s/km^2$
$7Q_2$	1.8	-	1.3	)	

The M.O.E. guideline on drought flow design is $7Q_{20}$. This implies that lower low flows will cause water quality violation in BOD and other wastes.

Flood Prone Area and Low Flow Analysis Study in the Kawartha Region
(MacLaren Plansearch, 1981)

This study developed a regression equation for predicting low flow estimates in the Kawartha region. The regression equations took the form:

$$\frac{\overline{Qi}}{DA} = 1.64 \times 10^{-3}\ SI^{3.171}\ ALS^{-0.116}$$

$$\frac{\overline{Qs}}{DA} = 6.90 \times 10^{-4}\ SI^{1.365}\ ALS^{-0.102}$$

where $\overline{Qi}$ = average minimum daily flow

$\overline{Qs}$ = average minimum summer flow
DA = drainage area
SI = index of average soil moisture holding capacity
ALS = % area covered by swamp or wet land

Approach for Frequency Analysis of Multiyear Drought Durations
(Lee, K.S., Sadeghipour, J., and J.A. Dracup, 1986)

An approach for frequency analysis of multiyear drought durations was presented. The problem of sample size is discussed with a technique for smoothing frequency-curve irregularities of drought durations. Piecewise linear regressions for the linearized termination probability curve define the parameters of the logistic model. The model then can be used to determine the return periods of multilinear droughts. This report, although interesting, is not directly applicable to the present investigations.

Determining Streamflows from Geomorphic Parameters (Osborn, J.F., 1974)

Osborn examined the many interconnected relationships of geomorphic parameters of basins to flows. An example of the basin characteristics interrelationship is that LS = 1.4 $(DA)^{0.6}$, where LS is stream length and DA is area. It is noted that the coefficient and power values vary for different geographic areas.

The equations for estimating average annual flow (QAA) took the form $QAA = C'' (P)^a (DA)^b$ where P is average annual precipitation and the coefficient and powers are determined from regional regressions.

It is noted that minimum or low flows tend to be more sensitive to a larger number of parameters than flood flows. Assuming linear flow-frequency relationships, a parameter Q7L1P was developed to relate the relative maximum size of low flow in one stream to another. This value was then regressed with basin parameters to establish $7Q_2$.

$$7Q_2 = B \left[\frac{(DA \cdot H)^{0.5}\ Q7L1P}{300(P)}\right]^m$$

where B is a coefficient
H is basin relief
P is slope of recurrence interval graph

The P parameter also represents a measure of the stability of the natural basin storage from which the low flow is derived. The value $7Q_2$ was then used as an index flow to predict other recurrence interval flows as:

$$7Q_{20} = \frac{P(\ Q_2)}{C}$$

where P is slope and C is a coefficient. For example,

$$\log 7Q_{20} = \log (P(7Q_2)) - \log C'$$

Relationships were also found between peak flows and low flows. It was determined that if basins were of the same average annual run-off then you assume C' is essentially the same and examine the peak flows, if they are different, then low flows must be different and the basins are not hydrologically similar.

Hydrologic Design Methodologies for Small Scale Hydro at Ungauged Sites (Acres, 1985)

This study developed a regression relationship between basin physiographic parameters and "turbinable flow" which was related to exceedance curves. Exceedance curves were non-dimensionalized by dividing flow values by the mean annual flow. For ungauged sites, a regression equation provided estimates of mean annual flow from values of MAR and area.

$$MAF = 0.0000369\ MAR \cdot DA$$

This was then related to a regional indexed curve to determine values of exceedance by examining the regional mean annual flow to the sight mean annual flow.

As well, two other methods were compared, proration and ARMA (Autoregressive Moving Average Methodology). It was determined that proration provided the best practical method for determining discharge. The proration formula took the form:

$$Q_{ijk} = QI_{ijk}(DA\ MAR)\ /\ (DAI\ MARI)$$

where i = year, j = month, k = day

The ARMA method was used to synthesize daily and monthly flows from required parameters within the basin over a time series.

Low Flow Studies (Institute of Hydrology, 1980)

The Institute of Hydrology (U.K.) analysed low flows using regression techniques. An innovative feature was the development of a geologic index called the baseflow index. This index can be determined from streamflow measurements (for equation see Condie, 1986). In ungauged areas, comparative areal methods can be used to estimate the BFI or it can be estimated from underlying geology.

Low flow duration curves were regressed from basin parameters. Then a comparative analysis of the change of slope for different d-day durations allowed for a prediction of any d-day low flow. In the study, much work was done to provide non-dimensional graphs and to linearize them for simplifying the estimation procedures.

The regional equations take the form:

$$Q_{95}\ (10) = C_1\ \mathrm{BFI} + C_2\ \mathrm{MAP} - C_3$$

$$\text{and } Q_{95}\ (10) = C_4\ \mathrm{BFI} + C_5\ \mathrm{LEN} - C_6$$

where MAP = mean annual precipitation
LEN = stream length
for region five.

As well, the slope is regressed from parameters as:

$$\log_{10} \mathrm{GRADMEN}\ Q_{95} = C_7\ \mathrm{MAP} - C_8\ Q_{95}(10) - C_9$$

These two regression equations were then used to estimate Q95 (d) for any d-day duration by the formula:

$$Q_{95}\ (d) = Q_{95}\ (10)\ [1 + (D-10)\ \mathrm{GRADMEN}\ Q_{95}].$$

Similar relationships were developed for mean annual minimum 10-day low flow MAM (10). Included in the report describing this five year study is a fairly extensive literature review which is paraphrased below.

Review of the Institute of Hydrology Background Review (Institute of Hydrology, 1980)

"Many examples worldwide employ catchment characteristics indexing catchment size, shape and climate and most refer to the additional need to consider the geology of the catchment in order to explain more of the variability of low flows. Wright (1970) presents a prediction equation for the lowest flow in a year using catchment slope and area as independent variables. Riggs (1973), Wesche et al (1973), and Skelton (1974), make use of the cross-sectional properties of streams to correlate low flows with neighbouring gauged catchment data. For the United Kingdom, general information on behaviour of British rivers is given by (Ward, 1968) and also (Rodda, 1976). The interaction between surface and groundwater for major aquifers is discussed in Ineson et al (1965). Much design work has been based on the lowest recorded flow. Flow duration curves and their applications in the U.K. are given in Hoyle (1963). They are discussed by Boulton (1965) where the concept of a Minimum Acceptable Flow is described and the factors likely to enter into its calculations are considered."

Regional Flood Frequency Analysis for Ontario Streams, Volume 2, Multiple Regression Method (Moin, S.M.A., and M.A. Shaw, 1986

This report includes a discussion of the Base Flow Index. The BFI was calculated and mapped for 2 flood regions identified in the Province.

The regression equations with BFI for predicting flood flows provided predictions superior to those derived using the secondary regression equations without the BFI parameter. The latter was found to be second only to drainage area as a significant parameter in describing variance of flood flows.

The BFI was found to be extremely sensitive to basin storage conditions and, therefore, could not be used in the primary regression equations for the northern region due to the large number of lakes and swamps.

Correlations with SCS soil groups indicated that BFI could be approximated as follows:

Soil Group A	> 0.60±
Soil Group B	0.45±
Soil Group C	0.30±
Soil Group D	< 0.25±

2.2 Summary of Literature Review

In summary, it was found that many investigations have produced low flow durations from 1 to 273 days in length, for return periods of 1 to 100 years. In general, it has been determined that the Gumbel III distribution best fits low flow data for gauged streams (Condie, Nix, 1975, Matalas, 1965 and Table 2.1). On the other hand, very few investigations have considered techniques for developing regionalized flow duration curves.

Parameters found to be significant in regression equations generally tended to be drainage area, base flow index, and mean annual precipitation. However, some parameters that have not been highly correlated in one region were found to be important in other regions (Institute of Hydrology, 1980).

From the available literature, it was decided to include the following parameters in development of the physiographic meteorologic and hydrometric data base; drainage area, (DA), mean annual snowfall (MAS), mean annual precipitation (MAP), mean annual runoff (MAR), area controlled by lakes and swamps (ACLS), Latitude (LAT), Longitude (LONG), Equivalent slope (EQSLP), 10/85 slope (OSLP), stream length (LEN), years of daily data (DYRS), and Base Flow Index (BFI).

It is evident from Table 2.1 that for extreme value analysis of low flows, the Gumbel III distribution is the most widely accepted.

3.0 DATA BASE

3.1 General

The Southwestern-West Central regions defined by the Ministry of Environment were used as the study area. One hundred and four hydrometric stations were identified in the region for this analysis based upon the period of record and other station characteristics. The stations considered are identified in Table 3.1. Sixty-five of these stations were used while ten of those remaining were set aside for testing of results. (Station screening and selection is discussed in Section 3.2.4.)

Analyses were undertaken to produce extreme value recurrence low flows and tables of flow exceedance values at each station. The methodology is discussed in Section 3.2 and results are summarized in the Low Flow Characteristics in Ontario* report (Appendix D) and on Figure 3.1 of this report. Station physiographic and meteorological characteristics were collected and are discussed in Section 3.3.

3.2 Low Flow Characteristics

3.2.1 Data Base

Existing low flow characteristics at the time of this study were several years out of date and, therefore, in conjunction with this study, the Low Flow Characteristic map was updated for this region*.

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* Cumming Cockburn Limited, "Low Flow Characteristics in Ontario", Ministry of the Environment, 1988

TABLE 3.1

Station List for Data Base

Station Number	Station Name	Screened Stations	Test Stations	Drainage Area (km^2)	Status	Reg./ Nat.	Period of Rec. (years)
02FA001	Sauble River at Sauble Falls			927	A	N	30
02FA002	Stokes River near Ferndale			50.5	A	N	11
02FB007	Sydenham River near Owen Sound			181	A	N	51
02FB009	Beaver River near Clarksburg	✓		572	A	R	28
02FB010	Bighead River near Meaford			293	A	R	30
02FC001	Saugeen River near Port Elgin			3960	A	N	73
02FC002	Saugeen River near Walkerton	✓		2150	A	N	73
02FC011	Carrick Creek near Carlsruhe			163	A	N	34
02FC012	South Saugeen River near Hanover			635	A	R	15
02FC013	North Saugeen River near Paisley			262	A	R	15
02FC015	Teeswater River near Paisley			663	A	N	15
02FC016	Saugeen River Above Durham			329	A	N	10
02FD001	Pine River at Lurgam		✓	154	A	N	13
02FE002	Maitland River below Wingham			1630	A	R	34
02FE003	Middle Maitland River near Listowel			77.7	A	R	34
02FE004	Maitland River near Donnybrook	✓		1760	A	R	39
02FE005	Maitland River above Wingham			528	A	R	33
02FE007	Little Maitland River at Bluevale			326	A	R	20
02FE008	Middle Maitland River near Belgrave			648	A	N	20
02FE009	South Maitland River at Summerhill			376	A	N	20
02FF002	Ausable River near Springbank			865	A	N	40
02FF004	South Parkhill Creek near Parkhill	✓		41.4	A	N	21
02FF007	Bayfield River near Varna			466	A	N	21
02FF008	Parkhill Ck above Parkhill Reservoir	✓		110	A	N	14
02GA003	Grand River at Galt	✓		3520	A	R	74

TABLE 3.1 (cont'd)

Station Number	Station Name	Screened Stations	Test Stations	Drainage Area (km^2)	Status	Reg./ Nat.	Period of Rec. (years)
02GA010	Nith River near Canning	0		1030	A	N	47
02GA014	Grand River near Marsville	✓		694	A	R	29
02GA015	Speed River below Guelph	✓		593	A	R	36
02GA016	Grand River below Shand Dam	✓		800	A	R	37
02GA018	Nith River at New Hamburg			552	A	N	37
02GA023	Canagagigue Creek near Elmira	✓		118	A	R	28
02GA024	Laurel Creek at Waterloo			59.6	A	R	27
02GA028	Conestoga River at Glen Allan	✓		578	A	R	28
02GA029	Eramosa River above Guelph			236	A	R	25
02GA030	Alder Creek near New Dundee			49.7	A	R	21
02GA031	Blue Springs Creek near Eden Mills			44.5	A	R	22
02GA032	O.A.C. Farm Gauge #5 at Guelph	✓		2.51	D	N	16
02GA033	Lutteral Creek Near Oustic			64.8	A	R	33
02GA034	Grand River at West Montrose			1170	A	R	20
02GA035	E.Canagagigue Ck near Floradale			27.7	D	N	15
02GA036	Canagagigue Creek near Floradale	0		17.9	D	N	15
02GA037	Schneider Creek at Kitchener	0		25.1	A	N	14
02GA038	Nith River above Nithburg			326	A	N	15
02GA039	Conestogo River above Drayton			272	A	N	14
02GA040	Speed River near Armstrong Mills			167	A	R	14
02GB001	Grand River at Brantford	✓		5210	A	R	50
02GB006	Horner Creek near Princeton			150	A	R	34
02GB007	Fairchild Creek near Brantford			360	A	N	23
02GB008	Whitemans Creek near Mount Vernon			383	A	R	26
02GB009	Kenny Creek near Burford	✓		91.9	A	N	25
02GB010	McKenzie Creek near Caledonia			171	A	R	26
02GC002	Kettle Creek at St. Thomas			329	A	N	19
02GC006	Big Creek near Delhi			363	A	R	32

TABLE 3.1 (cont'd)

Station Number	Station Name	Screened Stations	Test Stations	Drainage Area (km^2)	Status	Reg./ Nat.	Period of Rec. (years)
02GC007	Big Creek near Walsingham			591	A	R	32
02GC008	Lynn River at Simcoe			134	A	R	30
02GC010	Big Otter Creek at Tillsonburg			342	A	N	27
02GC012	Patterson Creek near Simcoe			51.3	A	R	23
02GC013	Dedrick Creek near Port Rowan			75.9	D	R	22
02GC015	L.Otter Ck near Straffordville			104	A	R	24
02GC017	Big Otter Creek above Otterville			93.2	A	R	23
02GC018	Catfish Creek near Sparta			287	A	N	23
02GC021	Venison Creek near Walsingham			68.4	A	R	21
02GC022	Nanticoke Creek at Nanticoke	✓		181	A	R	18
02GC026	Big Otter Creek near Calton			676	A	R	12
02GD001	Thames River near Ealing			1340	A	R	72
02GD003	North Thames River below Fanshawe Dam	✓		1450	A	R	62
02GD004	Middle Thames River at Thamesford			306	A	R	39
02GD005	North Thames River at St. Marys	✓		1080	A	R	36
02GD008	Medway River at London		✓	200	A	N	25
02GD009	Trout Creek near St. Marys			140	A	R	34
02GD010	Fish Creek near Prospect Hill		✓	150	A	N	36
02GD011	Cedar Creek at Woodstock			93.2	A	R	35
02GD012	Thames River at Woodstock			254	A	R	35
02GD013	Wye Creek near Thorndale	✓		38.9	A	N	16
02GD014	North Thames River near Mitchell	✓		319	A	R	33
02GD015	North Thames River near Thorndale			1340	A	R	34
02GD016	Thames River at Ingersoll	✓		518	A	R	30
02GD018	Avon River below Stratford			144	A	R	23
02GD019	Trout Creek near Fairview		✓	36.0	A	N	21
02GD020	Waubuno Creek near Dorchester			108	A	N	22
02GE002	Thames River at Byron	✓		3110	A	R	42

TABLE 3.1 (cont'd)

Station Number	Station Name	Screened Stations	Test Stations	Drainage Area (km^2)	Status	Reg./ Nat.	Period of Rec. (years)
02GE003	Thames River at Thamesville	✓		4300	A	R	32
02GE005	Dingman Creek below Lambeth			146	A	N	22
02GE006	Thames River near Dutton	✓		3760	A	R	16
02GE007	McGregor Creek near Chatham		✓	202	A	N	10
02GG002	Sydenham River near Alvinston			730	A	N	39
02GG004	Bear Creek above Wilkesport			609	D	N	21
02GG005	Sydenham River at Strathroy			172	A	N	21
02GG006	Bear Creek near Petrolia			267	A	N	21
02GG007	Sydenham River near Dresden			1240	D	N	18
02GH001	Sturgeon Creek near Leamington			14.2	A	N	15
02GH002	Ruscom River near Ruscom Station			125	A	N	16
02GH003	Canard River near Lukerville			159	A	N	11
02HA003	Niagara River at Queenston	✓		686,000	A	R	127
02HA006	Twenty Mile Creek at Balls Falls			293	A	N	30
02HA007	Welland River below Caistor Corners	✓		230	A	R	29
02HA014	Redhill Creek at Hamilton	✓		60.9	A	N	10
02HA019	Welland Canal Div. from Lake Erie	✓			A	R	127
02HB010	Spencer Creek at Dundas Crossing		✓	166	D	R	25
02HB011	Bronte Creek near Zimmerman		✓	235	A	R	22
02HB012	Grindstone Creek near Aldershot		✓	82.6	A	N	22
02HB013	Credit River near Orangeville		✓	62.2	A	R	20
02HB015	Spencer Creek near Westover		✓	63.5	A	N	16
02HB016	Bronte Creek at Progreston	✓		124	A	R	10

✓	station selected for testing or screened
0	30 day average low flow characteristics could not be calculated (arithmetic overflow)
A	station was active as of 1986
D	station was discontinued before 1986
N	stream is not considered to be regulated
R	stream is considered to be regulated

The available discharge data base to the end of 1985 was obtained for all relevant Water Survey of Canada monitoring locations (see discussion in Section 3.1). Extreme values were then calculated for various recurrence intervals and flow durations for annual series using the techniques discussed in Section 3.2.5. A computer drawn map depicting low flow characteristics was then produced in order to summarize key low flow statistics for Southwestern West Central regions (see Section 3.2.6 and Figure 3.1).

Data analysis and screening was then undertaken in order to assess the usefulness of the data at each location.

Stations with a minimum of ten years of record and stations active within the last five years were considered to have an appropriate record for the purpose of this investigation. These criteria were adopted so that the low flow characteristics would be representative of recent conditions.

3.2.2 Extreme Value Analysis

Average extreme low flows were determined and extracted for the 1, 3, 7, 15 and 30 day durations and are available as part of the background files.

An extreme value analysis was undertaken for each of the 1, 3, 7, 15 and 30-day durations for each of the stations.

Previous investigations have found that the Gumbel III distribution has resulted in the best fit for extreme value analysis of low flows on most Canadian rivers (see Section 2.0). However, for samples with large negative skewness, the 3-Parameter Log Normal Distribution has proven to give adequate results and was adopted for these stations (Condie, 1983). A technical discussion of the fitting procedure is given in the users manual and briefly in Appendix A.1.

Parameter estimation for fitting of distributions proceeded in order of maximum likelihood, smallest observed drought and moments. The procedure utilized was identified on summary tables together with the results of the analyses.

The results of the extreme value analysis for each station are given in "The Low Flow Characteristics of Ontario" study (Cumming Cockburn Limited, 1988) for various recurrence intervals for each duration. The format is illustrated in Table 3.2. The stations are identified by the Water Survey of Canada station number. The fitting method is identified by a 3 letter code, MAX, MOM, SOD, PLN which stand for; method of maximum likelihood, method of moments, method of smallest observed drought, and the three-parameter log normal distribution respectively (see also Appendix A.1 for additional information on the fitting procedures).

The next three parameters appearing in the summary table are general statistics of the data sample including the mean n-day duration flow (m^3/s), Standard deviation, Skew (G), and the coefficient of Variance (C). The next two columns of the tables give the number of years available (REC (YRS)) and the minimum average low flow for the particular duration (MIN).

Finally, the estimated flow for the various recurrence intervals are listed for each station.

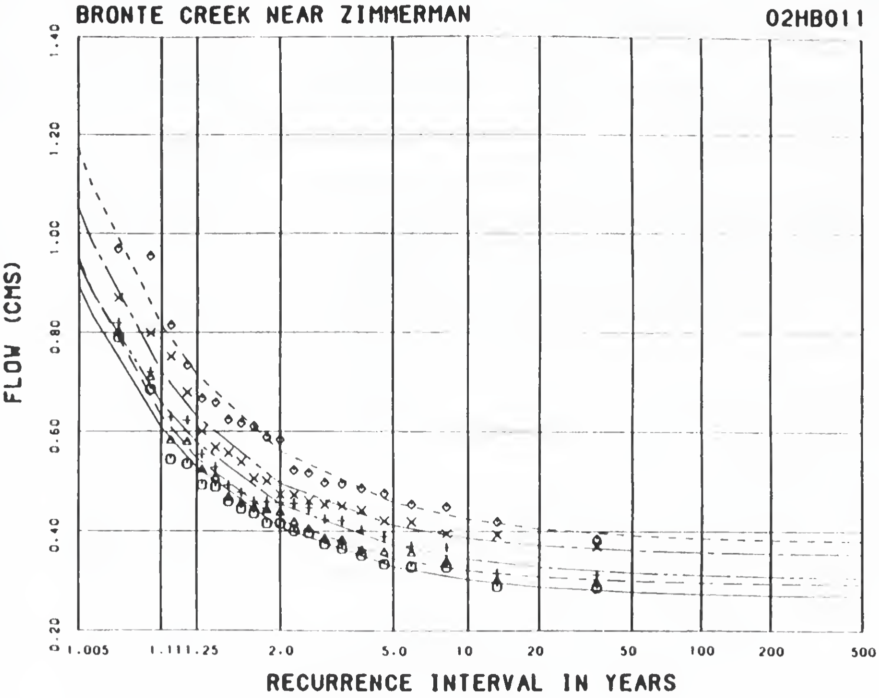
Extreme value frequency curves were plotted for each location and are available in "The Low Flow Characteristics of Ontario" (Appendix D, Cumming Cockburn, 1988). An example graph is given in Figure 3.2 which summarizes the curve fitting to the available data for the 1, 3, 7, 15 and 30 day durations for the Bronte Creek near Zimmerman, Water Survey of Canada Station Number 02HB011.

TABLE 3·2

EXAMPLE OF EXTREME VALUE TABULAR FORMAT

EXTREME VALUE LOW FLOW ANALYSIS FOR 7 DAY DURATION VALUES

STN#	METHOD	MEAN	STANDARD DEVIATION	G	C	REC (YRS)	MIN (m3/s)	RECURRENCE INTERVAL										
								1.005	1.010	1.111	1.250	2.0	5.0	10	20	50	100	200
02FA001	MAX	1.398	0.727	1.478	0.520	29	0.484	4.070	3.708	2.379	1.917	1.229	0.788	0.648	0.571	0.518	0.497	0.484
02FA002	SOD	0.038	0.039	0.883	1.014	11	0.003	0.205	0.178	0.089	0.062	0.026	0.008	0.004	0.001	0.000	0.000	0.000
02FB007	MAX	0.441	0.207	0.348	0.470	48	0.044	1.011	0.855	0.717	0.616	0.429	0.257	0.178	0.122	0.068	0.039	0.017
02FB009	MAX	2.201	0.564	-0.025	0.256	28	1.070	3.605	3.477	2.919	2.672	2.197	1.729	1.500	1.326	1.153	1.053	0.973
02FB010	MAX	0.564	0.203	1.859	0.360	29	0.295	1.256	1.167	0.832	0.711	0.524	0.395	0.351	0.326	0.307	0.299	0.295
02FC001	MAX	11.377	2.503	0.536	0.220	72	6.279	18.483	17.763	14.746	13.484	11.193	9.151	8.246	7.608	7.024	6.714	6.484
02FC002	MAX	6.571	1.769	0.265	0.269	72	3.200	11.622	11.104	8.943	8.045	6.429	5.006	4.384	3.951	3.558	3.352	3.200
02FC011	MAX	0.218	0.088	1.858	0.401	33	0.076	0.492	0.461	0.337	0.288	0.206	0.140	0.114	0.097	0.083	0.076	0.071
02FC012	MAX	0.942	0.172	-0.384	0.182	15	0.624	1.299	1.272	1.145	1.084	0.955	0.809	0.726	0.656	0.577	0.526	0.480
02FC013	SOD	1.442	0.153	-0.640	0.106	14	1.157	1.769	1.744	1.629	1.574	1.455	1.317	1.237	1.169	1.090	1.038	0.991
02FC015	MAX	1.417	0.390	0.413	0.275	15	0.759	2.515	2.401	1.927	1.732	1.383	1.080	0.949	0.858	0.777	0.735	0.704
02FC016	SOD	0.505	0.151	1.521	0.299	10	0.364	1.136	1.038	0.706	0.601	0.461	0.385	0.365	0.356	0.350	0.348	0.347
02FD001	SOD	0.010	0.020	1.973	1.961	13	0.000	0.121	0.095	0.027	0.014	0.003	0.000	0.000	0.000	0.000	0.000	0.000
02FE002	MAX	1.246	0.611	0.123	0.490	33	0.093	2.861	2.706	2.043	1.757	1.220	0.716	0.480	0.307	0.141	0.049	0.000
02FE003	MAX	0.022	0.017	3.492	0.803	34	0.004	0.080	0.072	0.042	0.032	0.018	0.009	0.007	0.005	0.005	0.004	0.004
02FE004	MAX	1.422	0.751	0.634	0.526	39	0.089	3.627	3.394	2.435	2.043	1.348	0.753	0.500	0.328	0.175	0.098	0.040
02FE005	MAX	0.599	0.224	0.417	0.374	33	0.215	1.248	1.178	0.898	0.783	0.578	0.400	0.324	0.272	0.225	0.201	0.183
02FE007	MAX	0.269	0.130	0.557	0.485	19	0.071	0.687	0.639	0.446	0.372	0.249	0.155	0.119	0.096	0.078	0.069	0.064
02FE008	SOD	0.285	0.096	1.042	0.338	19	0.169	0.634	0.588	0.418	0.357	0.264	0.202	0.182	0.170	0.162	0.158	0.156
02FE009	MAX	0.101	0.060	0.365	0.588	19	0.010	0.291	0.269	0.182	0.148	0.092	0.049	0.032	0.022	0.013	0.009	0.006
02FF002	MAX	0.307	0.143	0.784	0.466	39	0.089	0.777	0.722	0.504	0.420	0.284	0.181	0.142	0.118	0.099	0.090	0.084
02FF007	MAX	0.126	0.061	1.463	0.486	20	0.035	0.323	0.300	0.209	0.174	0.117	0.073	0.057	0.047	0.039	0.035	0.033
02FF008	SOD	0.007	0.008	0.791	1.119	13	0.000	0.043	0.037	0.018	0.012	0.005	0.001	0.000	0.000	0.000	0.000	0.000
02GA003	MAX	6.823	4.147	0.447	0.608	73	1.048	22.828	20.692	12.796	10.017	5.822	3.069	2.176	1.679	1.327	1.184	1.099
02GA010	MAX	2.082	0.537	-0.038	0.258	43	0.643	3.360	3.252	2.769	2.546	2.096	1.618	1.365	1.162	0.946	0.813	0.701
02GA014	SOD	0.252	0.192	0.673	0.762	27	0.000	0.922	0.838	0.518	0.400	0.215	0.084	0.039	0.012	0.000	0.000	0.000
02GA015	MAX	1.108	0.410	0.630	0.370	35	0.287	2.257	2.142	1.657	1.453	1.080	0.745	0.595	0.488	0.390	0.337	0.298
02GA016	MAX	1.677	0.799	0.296	0.476	36	0.255	3.974	3.735	2.744	2.335	1.607	0.976	0.704	0.516	0.348	0.262	0.198
02GA018	MAX	0.359	0.191	1.215	0.532	38	0.077	1.004	0.925	0.621	0.508	0.325	0.191	0.143	0.113	0.091	0.081	0.074
02GA023	MAX	0.195	0.106	0.632	0.546	30	0.042	0.563	0.517	0.341	0.277	0.174	0.102	0.076	0.061	0.050	0.045	0.041
02GA024	MAX	0.048	0.025	-0.138	0.530	26	0.003	0.110	0.104	0.080	0.069	0.048	0.027	0.017	0.008	0.000	0.000	0.000
02GA028	SOD	0.752	0.675	1.852	0.898	27	0.060	3.546	3.120	1.654	1.189	0.558	0.211	0.118	0.073	0.046	0.036	0.031
02GA029	MAX	0.562	0.189	0.369	0.336	24	0.173	1.063	1.015	0.811	0.722	0.554	0.394	0.319	0.263	0.209	0.179	0.155
02GA030	MAX	0.032	0.014	-0.076	0.438	20	0.003	0.065	0.062	0.050	0.044	0.032	0.020	0.014	0.009	0.004	0.001	0.000
02GA031	MAX	0.200	0.040	0.707	0.202	21	0.139	0.329	0.314	0.255	0.232	0.194	0.164	0.153	0.145	0.140	0.137	0.135
02GA032	SOD	0.001	0.001	0.129	1.034	17	0.000	0.008	0.007	0.003	0.002	0.001	0.000	0.000	0.000	0.000	0.000	0.000
02GA033	MAX	0.068	0.039	1.120	0.573	30	0.013	0.201	0.164	0.120	0.097	0.060	0.034	0.025	0.019	0.015	0.013	0.012
02GA034	MAX	2.902	0.913	-0.490	0.314	19	0.923	4.741	4.606	3.970	3.659	2.990	2.199	1.735	1.332	0.863	0.547	0.260
02GA035	MAX	0.068	0.012	0.093	0.183	14	0.047	0.101	0.098	0.084	0.078	0.067	0.057	0.053	0.050	0.047	0.045	0.044
02GA036	SOD	0.000	0.000	2.295	2.542	14	0.000	0.002	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
02GA037	MAX	0.054	0.015	0.683	0.272	14	0.035	0.120	0.110	0.077	0.066	0.058	0.040	0.038	0.036	0.035	0.035	0.035
02GA038	SOD	0.068	0.051	2.702	0.752	14	0.038	0.320	0.272	0.129	0.092	0.050	0.034	0.031	0.029	0.029	0.029	0.029



LEGEND

ACTUAL DATA	GUMBEL ANALYSIS	DAY DURATION
●	——————	1
▲	— — — —	3
✚	—— - ——	7
✖	—— - - ——	15
◆	- - - - -	30

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Consulting Engineers and Planners

LOW FLOW FREQUENCY ANALYSIS
EXAMPLE GRAPH

FIGURE 3·2

3.2.3 Flow Duration Analysis

The daily discharge data was extracted for each station and analysed to derive flow duration curves. The flow duration curves were summarized both numerically and graphically for each station ("The Low Flow Characteristics of Ontario" (Appendix D, Cumming Cockburn, 1988)). The results are summarized in tabular format at 1% intervals across the flow duration curve. An example summary table is given in Table 3.3. The first column "PER" refers to the percentage of the period of record that the tabulated flow was equalled or exceeded (all flows are in m^3/s). The annual flow duration information are listed in column 2 for the percentage summarized in column 1. Therefore, the largest daily flow recorded for this station up to 1986 is 29.7 m^3/s, found in the first row at 0 percent. More significantly for this study are the low flows summarized in the latter section of the table which have been exceeded 90, 95 and 100 percent of the time for the period of record.

The 50 percent value (1.69 m^3/s) refers to the median daily flow for the period of record of the flow series and can be compared to the mean value 2.76 m^3/s summarized in the last row of the table.

3.2.4 Maps

Selected low flow characteristics were extracted and summarized on a map for this region (see Figure 3.1). The station locations are identified by a Δ located on the rivers at the point of discharge measurement and the selected data is summarized in an information box, an example of which is depicted in Figure 3.3.

The stations are identified by the 7 digit Water Survey Station Number and this is followed by a regulation code. The "R" indicates that data collected at the station is affected by regulation, "N" means the station data are natural or non-regulated. The boxes on the left from the top refer to the average 7-day flow (m^3/s)

EXAMPLE TABLE 3.3

SUMMARY TABLE FROM FLOW DURATION ANALYSIS 02HB011 BRONTE CREEK NEAR ZIMMERMAN
YEARS OF RECORD: 21 STATION AREA: 235

PER	ANNUAL	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0	29.700	22.700	23.000	28.900	29.700	21.500	10.300	12.900	9.080	12.900	15.700	10.500	17.500
1	15.200	7.650	15.700	21.200	21.700	10.100	5.300	6.370	3.970	7.690	8.130	9.380	10.800
2	12.600	6.460	14.300	17.600	19.100	8.670	4.470	4.050	3.430	5.780	6.740	8.340	8.210
3	10.700	5.970	13.200	18.200	17.100	7.990	3.990	3.370	3.060	4.590	6.160	7.160	7.700
4	9.710	5.510	12.400	15.300	15.500	7.330	3.670	2.860	2.520	3.900	5.590	6.300	7.190
5	8.880	5.270	11.300	15.000	14.900	6.770	3.420	2.580	2.410	3.320	5.130	5.950	6.800
6	8.240	4.730	9.630	14.400	14.000	6.400	3.340	2.290	2.290	3.070	4.670	5.140	6.440
7	7.650	4.530	8.410	13.700	13.400	5.970	3.230	2.170	2.140	2.770	4.500	4.870	6.170
8	7.080	4.250	7.890	13.200	12.700	5.800	3.110	2.040	2.000	2.520	4.020	4.500	6.000
9	6.560	4.170	7.080	12.700	12.100	5.540	3.050	1.940	1.940	2.310	3.820	4.360	5.790
10	6.210	3.960	6.570	12.200	11.600	5.350	2.990	1.840	1.760	2.260	3.510	4.160	5.460
11	5.860	3.820	5.950	12.000	11.200	5.100	2.900	1.800	1.700	2.080	3.310	3.990	5.320
12	5.520	3.720	5.660	11.300	10.700	4.980	2.810	1.700	1.590	2.010	3.050	3.940	5.210
13	5.230	3.680	5.380	11.100	10.500	4.850	2.750	1.650	1.540	1.980	2.930	3.870	5.100
14	5.000	3.540	5.100	10.900	10.100	4.690	2.660	1.610	1.500	1.910	2.630	3.790	4.960
15	4.740	3.400	4.840	10.500	9.800	4.620	2.580	1.580	1.450	1.830	2.540	3.740	4.740
16	4.520	3.310	4.470	10.500	9.600	4.470	2.510	1.530	1.400	1.750	2.410	3.710	4.590
17	4.300	3.250	4.250	10.300	9.370	4.370	2.410	1.490	1.380	1.710	2.330	3.650	4.420
18	4.160	3.170	3.900	10.100	9.150	4.280	2.360	1.460	1.360	1.670	2.220	3.610	4.320
19	4.000	3.110	3.680	9.800	8.960	4.220	2.250	1.440	1.310	1.640	2.160	3.570	4.250
20	3.880	3.030	3.510	9.670	8.780	4.120	2.180	1.380	1.280	1.600	2.080	3.540	4.220
21	3.740	2.950	3.450	9.570	8.690	4.000	2.130	1.350	1.240	1.530	2.020	3.450	4.190
22	3.650	2.920	3.370	9.430	8.500	3.960	2.100	1.320	1.220	1.500	1.940	3.400	4.110
23	3.530	2.890	3.200	9.300	8.350	3.910	2.020	1.310	1.190	1.470	1.920	3.340	4.010
24	3.430	2.830	3.140	9.080	8.160	3.840	1.980	1.270	1.180	1.390	1.880	3.280	3.940
25	3.340	2.750	2.990	8.920	8.040	3.740	1.950	1.250	1.160	1.340	1.820	3.260	3.890
26	3.260	2.680	2.830	8.800	7.930	3.660	1.910	1.230	1.120	1.310	1.790	3.200	3.820
27	3.160	2.610	2.780	8.600	7.700	3.620	1.880	1.200	1.100	1.260	1.770	3.150	3.770
28	3.090	2.550	2.690	8.500	7.500	3.550	1.830	1.180	1.080	1.210	1.700	3.110	3.740
29	3.000	2.490	2.660	8.390	7.390	3.500	1.790	1.160	1.060	1.180	1.670	3.030	3.650
30	2.920	2.450	2.580	8.240	7.280	3.430	1.760	1.140	1.050	1.150	1.660	3.000	3.600
31	2.830	2.410	2.550	8.070	7.180	3.390	1.710	1.110	1.030	1.100	1.640	2.950	3.590
32	2.750	2.350	2.520	8.000	7.050	3.340	1.670	1.090	1.010	1.080	1.620	2.920	3.540
33	2.670	2.270	2.460	7.800	6.930	3.280	1.660	1.080	1.000	1.060	1.610	2.890	3.460
34	2.600	2.270	2.440	7.590	6.820	3.260	1.620	1.060	0.983	1.020	1.580	2.830	3.430
35	2.520	2.270	2.380	7.370	6.680	3.230	1.590	1.040	0.964	0.994	1.550	2.760	3.400
36	2.460	2.210	2.350	7.110	6.600	3.140	1.570	1.030	0.949	0.974	1.540	2.720	3.350
37	2.410	2.190	2.290	7.000	6.460	3.090	1.530	1.010	0.940	0.951	1.500	2.660	3.280
38	2.350	2.150	2.220	6.800	6.430	3.090	1.500	0.994	0.928	0.927	1.480	2.640	3.200
39	2.290	2.120	2.120	8.650	6.400	3.020	1.480	0.974	0.914	0.912	1.450	2.600	3.150
40	2.240	2.100	2.020	6.430	6.340	2.970	1.470	0.966	0.895	0.898	1.410	2.560	3.090
41	2.170	2.070	1.930	6.200	6.210	2.920	1.440	0.955	0.882	0.881	1.370	2.520	3.060
42	2.120	2.040	1.870	6.040	6.090	2.890	1.430	0.934	0.875	0.871	1.350	2.470	3.000
43	2.060	1.980	1.700	5.720	6.030	2.860	1.400	0.922	0.867	0.867	1.310	2.410	2.920
44	1.990	1.980	1.620	5.660	5.920	2.810	1.370	0.911	0.858	0.852	1.290	2.380	2.810
45	1.940	1.950	1.620	5.490	5.850	2.800	1.350	0.901	0.841	0.841	1.270	2.350	2.750
46	1.890	1.900	1.610	5.380	5.720	2.760	1.340	0.886	0.824	0.827	1.240	2.300	2.670
47	1.840	1.870	1.590	5.130	5.610	2.740	1.320	0.878	0.816	0.818	1.210	2.250	2.650
48	1.790	1.840	1.590	5.050	5.500	2.700	1.320	0.850	0.799	0.812	1.190	2.210	2.610
49	1.750	1.810	1.560	4.990	5.440	2.660	1.300	0.835	0.789	0.804	1.170	2.150	2.550

EXAMPLE TABLE 3·3 (CONTN.)

SUMMARY TABLE FROM FLOW DURATION ANALYSIS 02HB011 BRONTE CREEK NEAR ZIMMERMAN
YEARS OF RECORD: 21 STATION AREA: 235

PER	ANNUAL	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
50	1.690	1.780	1.550	4.910	5.340	2.620	1.290	0.807	0.779	0.798	1.150	2.110	2.520
51	1.650	1.760	1.530	4.790	5.250	2.560	1.280	0.784	0.763	0.780	1.130	2.080	2.500
52	1.620	1.750	1.490	4.630	5.210	2.510	1.250	0.779	0.755	0.771	1.100	2.040	2.460
53	1.590	1.740	1.460	4.530	5.130	2.490	1.250	0.770	0.744	0.765	1.080	1.980	2.430
54	1.550	1.700	1.430	4.450	5.030	2.450	1.230	0.760	0.738	0.756	1.060	1.890	2.390
55	1.520	1.670	1.420	4.220	4.930	2.410	1.230	0.750	0.728	0.748	1.030	1.860	2.370
56	1.490	1.630	1.420	4.110	4.830	2.390	1.210	0.733	0.720	0.739	1.020	1.830	2.350
57	1.450	1.610	1.400	3.990	4.750	2.350	1.200	0.728	0.708	0.731	1.010	1.760	2.310
58	1.420	1.590	1.390	3.940	4.680	2.340	1.180	0.722	0.697	0.725	0.990	1.730	2.270
59	1.380	1.560	1.360	3.780	4.590	2.310	1.170	0.711	0.688	0.716	0.973	1.680	2.220
60	1.350	1.540	1.310	3.710	4.530	2.270	1.170	0.708	0.682	0.711	0.940	1.630	2.170
61	1.310	1.520	1.270	3.650	4.470	2.230	1.150	0.699	0.677	0.708	0.920	1.610	2.150
62	1.290	1.510	1.250	3.540	4.400	2.200	1.140	0.691	0.668	0.699	0.900	1.570	2.120
63	1.250	1.500	1.250	3.430	4.300	2.170	1.120	0.685	0.657	0.685	0.895	1.560	2.100
64	1.220	1.500	1.200	3.400	4.250	2.150	1.110	0.680	0.651	0.673	0.883	1.510	2.040
65	1.190	1.500	1.190	3.300	4.220	2.120	1.100	0.671	0.640	0.668	0.869	1.480	1.980
66	1.160	1.470	1.160	3.260	4.160	2.080	1.090	0.663	0.630	0.657	0.858	1.440	1.940
67	1.130	1.420	1.130	3.260	4.080	2.080	1.080	0.657	0.623	0.646	0.850	1.400	1.890
68	1.100	1.400	1.120	3.200	4.050	2.040	1.070	0.654	0.612	0.640	0.833	1.370	1.870
69	1.070	1.360	1.100	3.140	3.990	2.020	1.050	0.648	0.606	0.634	0.827	1.350	1.850
70	1.050	1.340	1.080	3.060	3.940	1.990	1.050	0.645	0.600	0.629	0.809	1.300	1.810
71	1.020	1.320	1.060	2.970	3.850	1.940	1.030	0.631	0.593	0.623	0.784	1.260	1.800
72	0.991	1.310	1.040	2.890	3.790	1.930	1.010	0.623	0.580	0.623	0.776	1.240	1.760
73	0.966	1.300	1.030	2.800	3.710	1.900	1.000	0.617	0.572	0.612	0.765	1.190	1.730
74	0.937	1.280	1.020	2.760	3.570	1.880	0.988	0.612	0.568	0.602	0.750	1.180	1.690
75	0.912	1.220	1.000	2.730	3.510	1.840	0.977	0.602	0.561	0.598	0.742	1.150	1.660
76	0.886	1.190	0.980	2.680	3.450	1.810	0.960	0.592	0.555	0.589	0.733	1.120	1.640
77	0.864	1.150	0.967	2.550	3.400	1.800	0.940	0.583	0.547	0.581	0.719	1.080	1.630
78	0.841	1.120	0.949	2.450	3.280	1.770	0.931	0.568	0.541	0.573	0.711	1.060	1.590
79	0.810	1.070	0.934	2.380	3.230	1.720	0.923	0.561	0.538	0.566	0.705	1.050	1.560
80	0.782	1.030	0.920	2.320	3.180	1.690	0.905	0.555	0.532	0.549	0.692	1.030	1.540
81	0.760	1.000	0.860	2.280	3.140	1.670	0.888	0.547	0.521	0.539	0.679	0.993	1.500
82	0.736	0.940	0.830	2.180	3.090	1.640	0.867	0.538	0.515	0.529	0.668	0.971	1.460
83	0.716	0.720	0.800	2.050	3.030	1.600	0.861	0.532	0.500	0.521	0.660	0.960	1.420
84	0.699	0.600	0.790	1.950	2.950	1.570	0.844	0.523	0.493	0.513	0.654	0.915	1.400
85	0.679	0.572	0.765	1.850	2.920	1.550	0.838	0.513	0.481	0.499	0.646	0.887	1.370
86	0.660	0.558	0.700	1.830	2.860	1.510	0.810	0.501	0.476	0.493	0.637	0.867	1.330
87	0.643	0.538	0.670	1.770	2.780	1.490	0.784	0.494	0.470	0.481	0.633	0.861	1.300
88	0.626	0.538	0.634	1.700	2.740	1.450	0.776	0.490	0.464	0.467	0.623	0.844	1.300
89	0.612	0.530	0.595	1.550	2.670	1.440	0.759	0.481	0.459	0.457	0.614	0.810	1.300
90	0.595	0.515	0.540	1.520	2.610	1.400	0.736	0.476	0.450	0.447	0.603	0.756	1.260
91	0.570	0.507	0.510	1.390	2.520	1.370	0.708	0.467	0.442	0.439	0.595	0.708	1.210
92	0.549	0.500	0.498	1.190	2.510	1.340	0.695	0.459	0.433	0.433	0.567	0.674	1.180
93	0.533	0.493	0.490	1.090	2.430	1.300	0.681	0.450	0.428	0.430	0.561	0.660	1.150
94	0.513	0.487	0.480	1.080	2.360	1.250	0.657	0.447	0.413	0.422	0.544	0.637	1.020
95	0.496	0.481	0.453	0.934	2.290	1.200	0.646	0.439	0.400	0.416	0.527	0.620	0.878
96	0.476	0.479	0.447	0.900	2.230	1.170	0.634	0.433	0.374	0.399	0.515	0.600	0.765
97	0.455	0.464	0.425	0.736	2.120	1.120	0.600	0.408	0.365	0.382	0.505	0.583	0.665
98	0.433	0.458	0.425	0.640	2.030	1.060	0.561	0.394	0.345	0.374	0.496	0.564	0.631
99	0.399	0.311	0.425	0.590	1.780	0.973	0.515	0.340	0.328	0.357	0.470	0.541	0.614
100	0.286	0.311	0.419	0.500	1.610	0.934	0.433	0.289	0.286	0.328	0.433	0.459	0.600
MEAN	2.759	2.210	2.827	6.213	6.458	3.148	1.633	1.124	1.010	1.243	1.706	2.469	3.092

with a recurrence interval of 2, 5, 10 and 20 years, followed by the minimum average 7-day flow and the period of record for the station. The values shown on the right are the flows (m^3/s) equalled or exceeded for the available period of record 5, 50, 75, 95, and 99 percent of the time followed by the station drainage area in km^2.

Station names are listed along with the station numbers for identification purposes, on the map for this region.

3.2.5 Data Analysis and Screening

The available data for each station were reviewed to delete stations which contained 30% or more zero low flow occurrences for the different low flow durations. The stations which were subsequently omitted from the analysis are tabulated and discussed in Section 3.2.6.

A draft version of the Low Flow Frequency Analysis program was obtained from Environment Canada for use in the investigation (Pilon, 1987). This program contains a set of data analysis and checking modules suitable for data screening and analysis (Pilon, 1985). However, at present there is some question concerning the methodology for checking Independence for low flow data series (personal communication Water Resources Branch, Environment Canada)*.

It must also be expected that a certain number of stations which are tested will randomly "fail" any given statistical test. Therefore, the binomial distribution was used to calculate the number of expected random failures over the entire data base for each region in order to assess the suitability of the low flow data on a regional basis. A tabulation of theoretical and actual "failure" results is summarized in Table 3.4 and discussed in Section 3.2.6.

LOW-FLOW CHARACTERISTICS OF STREAMS
IN
NORTHWESTERN ONTARIO

Ministry of the Environment
Water Resources Branch

7Q2	5%DUR
7Q5	50%DUR
7Q10	75%DUR
7Q20	95%DUR
MIN DAY	99%DUR
PERIOD	AREA
STATION ● RC	

7Q20	7-DAY AVERAGE LOW-FLOW WITH RECURRENCE OF 20 YEARS (CUBIC METERS /SECOND)
95% DUR	FLOW EXCEEDED 95% OF RECORD (CUBIC METERS /SECOND)
PERIOD	PERIOD OF RECORD (YEARS)
AREA	DRAINAGE AREA (SQUARE KILOMETERS)
MIN DAY	LOWEST 1 DAY AVERAGE FLOW (CUBIC METERS /SECOND)
STATION ●	WSC STATION IDENTIFICATION
RC	REGULATION IDENTIFICATION

Cumming Cockburn Limited
Consulting Engineers and Planners

INFORMATION KEY FOR
LOWFLOW CHARACTERISTIC MAPS

Figure 3.3

The tests were also re-evaluated for various data groupings reflecting the length of record and degree of regulation. The period of record was subdivided into stations with less than 20 years of record and stations with greater than or equal to 20 years of record. The effect of regulation was examined by further subdivision of the data base according to regulated and non-regulated stations (see Table 3.4).

3.2.6 Screening Results

Table 3.5 lists the stations which were not considered to possess a suitable low flow data base for the purposes of this investigation. Hence these stations were not included in the regionalization analysis. These stations were excluded for the following reasons:

i) Zero Flows

Prior to undertaking the extreme value analyses all data sets containing 30% or more zero low flows for all durations were identified and removed from the data base (see Table 3.3).

ii) Arithmetic Overflow

For 5 stations, the integral of the probability function

$$F(x) = 1 - \exp\left[- \frac{(x - e)^a}{(u - e)}\right]$$

---

* The trend and independence test assumed a lag of 1 year between samples while in actual fact greater than 1.5 year or less than 0.5 year lag between samples may exist. New subroutines were created to exclude values not 1 year lag from testing procedures, re-analysing the data with the new modules is beyond the scope of this study.

TABLE 3.4

Extreme Value Data Series Screening Summary

Summary of Data Screening - All Stations

Southwest and West Central Region

Day Duration	Independence						Trend						Randomness					
	1%			5%			1%			5%			1%			5%		
	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.
1	72	26	0	66	32	0	57	40	0	44	54	0	17	84	0	67	34	0
3	71	27	0	68	30	0	54	44	0	43	55	0	18	83	0	68	33	0
7	72	26	0	66	32	0	58	40	0	42	56	0	19	82	0	71	30	0
15	74	24	0	67	31	0	57	41	0	44	54	0	17	84	0	73	28	0
30	71	27	0	65	33	0	54	44	0	41	57	0	17	84	0	70	31	0
TOTAL	360*	130		332	158		280	210		214	276		88	417		349	156	

Summary of Data Screening
Non Regulated Stations With A Period of Record Greater Or Equal to 20 Years

Southwest and West Central Region

Day Duration	Independence						Trend						Randomness					
	1%			5%			1%			5%			1%			5%		
	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.
1	20	6	0	19	7	0	18	8	0	13	13	0	6	20	0	20	6	0
3	20	6	0	20	6	0	17	9	0	14	12	0	7	19	0	21	5	0
7	20	6	0	19	7	0	18	8	0	15	11	0	8	18	0	23	3	0
15	21	5	0	19	7	0	17	9	0	13	13	0	6	20	0	22	4	0
30	21	5	0	17	9	0	14	12	0	10	16	0	6	20	0	20	6	0
TOTAL	102*	28		94	36		84	46		65	65		33	97		106	24	

Summary of Data Screening
Non Regulated Stations With A Period Of Record Less Than 20 Years

Southwest and West Central Region

Day Duration	Independence						Trend						Randomness					
	1%			5%			1%			5%			1%			5%		
	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.
1	16	2	0	16	2	0	16	2	0	14	4	0	4	16	0	13	7	0
3	16	2	0	16	2	0	16	2	0	14	4	0	4	16	0	12	8	0
7	17	1	0	17	1	0	16	2	0	12	6	0	4	16	0	14	6	0
15	18	0	0	17	1	0	17	1	0	11	7	0	4	16	0	16	4	0
30	18	0	0	18	0	0	17	1	0	15	3	0	4	16	0	17	3	0
TOTAL	85*	5		84	6		32	8		66	24		20	80		72	28	

Summary of Data Screening
Regulated Stations With A Period Of Record Greater Or Equal To 20 Years

Southwest and West Central Region

Day Duration	Independence						Trend						Randomness					
	1%			5%			1%			5%			1%			5%		
	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.
1	30	18	0	25	23	0	18	30	0	13	35	0	5	44	0	28	21	0
3	29	19	0	26	22	0	16	32	0	12	35	0	5	44	0	29	20	0
7	29	19	0	24	24	0	19	29	0	12	36	0	5	44	0	28	21	0
15	29	19	0	25	23	0	18	30	0	16	32	0	5	44	0	29	20	0
30	26	22	0	24	24	0	18	30	0	12	36	0	5	44	0	27	22	0
TOTAL	143*	97		124	116		89	151		65	175		25	220		141	104	

Summary of Data Screening
Regulated Stations With A Period Of Record Less Than 20 Years

Southwest and West Central Region

Day Duration	Independence						Trend						Randomness					
	1%			5%			1%			5%			1%			5%		
	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.	Sig.	Not	Per.
1	6	0	0	6	0	0	5	1	0	4	2	0	2	4	0	6	0	0
3	6	0	0	6	0	0	5	1	0	3	3	0	2	4	0	6	0	0
7	6	0	0	6	0	0	5	1	0	3	3	0	2	4	0	6	0	0
15	6	0	0	6	0	0	5	1	0	4	2	0	2	4	0	6	0	0
30	6	0	0	6	0	0	5	1	0	4	2	0	2	4	0	6	0	0
TOTAL	30*	0		30	0		25	5		18	12		10	20		30	0	

Dur : The duration the data set represents ie average 30 day low flow
Sig The number of stations which show significant dependence, trend, non randomness
Not : The number of stations which show independence, free from trend, and randomness
Per The percent binomial probability that this number of stations would fail the non parametric tests

* TOTAL REFERS TO ALL STATIONS FOR ALL DURATIONS

Stations with Unacceptable Low Flow Data Set

Station	Station Name	Reason for Removal
02FB009	Beaver River near Clarksburg	Heavily regulated
02FC002	Saugeen River near Walkerton	Multiple Gauge on river
02FE004	Maitland River near Donnybrook	Multiple Gauge on river
02FF004	South Parkhill Creek near Parkhill	Arithmetic overflow
02FF008	Parkhill Creek above Parkhill Reservoir	Arithmetic overflow
02GA003	Grand River at Galt	Heavily regulated
02GA010	Nith River near Canning	30 day Duration not calculated
02GA014	Grand River near Marsville	Heavily regulated
02GA015	Speed River below Guelph	Multiple gauge on river (heavily regulated)
02GA016	Grand River below Shand Dam	Heavily regulated
02GA023	Canagagigue Creek near Elmira	Heavily regulated
02GA028	Conestoga River at Glen Allan	Heavily regulated
02GA032	O.A.C. Farm Gauge #5 at Guelph	30% or more zero low flows
02GA034	Grand River at West Montrose	Heavily regulated
02GA036	Canagagigue Creek near Floradale	30 day Duration not calculated
02GA037	Schneider Creek at Kitchener	30 day Duration not calculated
02GB001	Grand River at Brantford	Multiple gauge on river (heavily regulated)
02GB009	Kenny Creek near Burford	Arithmetic overflow
02GC022	Nanticoke Creek at Nanticoke	Heavily regulated
02GD003	North Thames River below Fanshawe Dam	Multiple gauge on river (heavily regulated)
02GD005	North Thames River at St. Marys	Multiple gauge on river (heavily regulated)
02GD013	Wye Creek near Thorndale	Arithmetic overflow
02GD014	North Thames River near Mitchell	Heavily regulated
02GD016	Thames River at Ingersoll	Heavily regulated
02GE002	Thames River at Byron	Multiple gauge on river (heavily regulated)
02GE003	Thames River at Thamesville	Multiple gauge on river (heavily regulated)
02GE006	Thames River near Dutton	Multiple gauge on river (heavily regulated)
02HA003	Niagara River at Queenston	Only 1 day duration could be extracted
02HA007	Welland River below Caistor Corners	Diversion Channel/Heavily regulated
02HA014	Redhill Creek at Hamilton	Arithmetic overflow
02HA019	Welland Canal Div. from Lake Erie	30% or more zero low flows
02HB016	Bronte Creek at Progreston	Multiple station

where e is the lower bound parameter
u is the characteristic drought
a is the shape parameter

could not be obtained since the function causes an arithmetic overflow (i.e. the version of the program automatically terminates calculations). Hence, extreme value analysis could not be undertaken using such data without program modifications which were beyond the scope of this investigation. Therefore, these data sets, which are identified in Table 3.5, were deleted from the present study. Additional work should be undertaken to modify the program in order to obtain suitable curve fitting results.

iii) High Outliers

The analysis of stations with very large low flows (greater than 1000 m^3/s) could not be completed and hence were identified and removed from the analysis (e.g. 02HA003 - Niagara River at Queenston). Additional research investigations are required to identify reasons for program termination in such cases.

iv) Multiple Stations

It was determined that large river systems may have several streamflow gauges at several locations along the channel. The use of all such highly correlated data could adversely bias the development of regionalization methods. Therefore, only representative gauges for such streams were retained for further analysis.

v) Heavily Regulated

Low flows on heavily regulated streams (i.e. Thames River and Grand River systems) are affected through the use of reservoirs for low flow augmentation. Since the main focus of this study is to produce a method for investigating low flows for ungauged watersheds, stations indicating a high degree of regulation were excluded from the data base. Some "regulated" stations were retained and assigned a regulatory code representing degree of regulation. Subsequent simple correlation analysis confirmed that these stations could be retained in the data set due to insignificant levels of correlation.

vi) Statistical Tests

Statistical data analysis tests were undertaken as outlined in Section 3.2.5 and described in more detail in Appendix A.2. The available test statistics were recently made available as part of the LFA (Pilon and Jackson, 1987) low flow package and their application here is one of the first in an investigation of low flow characteristics.

In general, it was found that a significant number of stations "failed" the non-parametric tests. Therefore, taken over the entire data base, application of these tests has indicated that the available data base of extreme low flows may exhibit some trend and dependence with some possibility of non-random characteristics.

The data were further analysed by subdivision of the available data set according to length of record (i.e. $\geq$20 years and <20 years) and according to regulation code. However, it was found that neither the length of record, nor the possible effects of regulation could account for the conclusions of the test results. One explanation could be that the available record lengths are too short to permit reasonable application and interpretation of these non-parametric test results. A stronger possibility is that the available low flow data sets do exhibit trend and non random characteristics, which could possibly be attributed to slow cyclic change in groundwater levels or to climatic trends. Additional testing was beyond the scope of the current investigations. However, further studies are recommended since these results may call into question the basic assumptions underlying application of the extreme value analysis technique for analysis of low flow characteristics.

Stations not passing the statistical screening were not removed from the analysis as there would be too few stations remaining.

3.2.7 Summary of Data Analysis and Low Flow Characteristics

Application of various non-parametric tests was undertaken for the available data base for the first time in Ontario.* The test results indicate that the available data base of extreme low flows may exhibit some trend and dependence with some possibility of non-random characteristics. Previous wide-spread application of the tests utilized have not been found in the literature for low flows. The average length of record for the stations analysed in this region is 26 years. It is possible that the available record lengths are too short to permit reasonable application and interpretation of these non-parametric test results. Another possibility, which should be investigated in more detail, is that the available low flow data sets do exhibit trend and non-random characteristics. The latter could possibly be attributed to slow cyclic changes in groundwater levels or climatic trends. This should be investigated in more detail since the underlying assumptions of the extreme value and subsequent regression analyses are called into question.

The Gumbel Extreme Value Distribution was found to adequately fit the available low flow series for various low flow durations. Data for some stations could not be fit due to either a large number of zero flows, numerical computational problems, or very large low flows recorded at some locations. Additional research investigations are required to develop suitable low flow analysis techniques for such locations.

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* The analysis was done in conjunction with "Low Flow Characteristics in Ontario Study", Cumming Cockburn Limited, 1988

Flow duration analysis were undertaken on a total of just over 100 stations, both on an annual and monthly basis. Extreme value analysis were also undertaken on an annual basis for just over 100 stations. A total of 65 stations were retained for analysis and 10 for additional testing of results.

The data analyses were undertaken for both regulated and unregulated data series. Therefore care should be taken in comparison and interpretation of results, notably for data series which may include the effects of regulation.

It was found that low flows are consistently lower in the Southwestern/West Central regions than the Provincial average. Mean low flow averages for the Province range from 10 to 15 m^3/s while they were found to range from 2 to 3 m^3/s for the Southwestern West Central Region for 1 to 30 day averages. The mean 7-day low flow for all stations analysed for this region was found to be 2.44 m^3/s and the mean unit area $7Q_{20}$ low flow is 0.70 $l/s/km^2$ with a standard deviation of 0.86. The regional differences of mean 7 day low flow values may be attributed to a function of the hydrometric network regional differences in watershed areas.

Figure 3.1 summarizes the following low flow characteristics:

- 7 day extreme values for the 2, 5, 10 and 20 year recurrence intervals
- flows which were equalled or exceeded over the available period 5, 50, 75, 95 and 99 percent of the time

Data analysis and management technique are now available which would allow efficiently updating the present analyses on a frequent basis. In our opinion, the low flow analyses should be updated every five years in order to provide reasonably accurate information for investigations requiring low flow information.

3.3 Physiographic and Hydrometeorologic Data

3.3.1 Criteria

Several criteria were used to identify physiographic and climatic parameters which might be suitable for use in regionalizing low flow characteristics. These are discussed as follows:

i) Statistical Significance

When undertaking a multivariate analysis, the variables chosen must make a contribution to explaining the variance of the low flows. The significant experience in undertaking similar investigations (discussed in Section 2.0) was used to identify parameters which have proven to be statistically significant in predicting low flows.

ii) Physical Reality

Wherever possible, variables should be selected based on hydrologic significance. That is, the parameters should have some physical meaning with regard to estimate of low flows.

iii) Reliability of Computation

It is preferable to select parameters which can easily be computed in a reliable manner by users who may not be familiar with regression procedures or the details of the statistical concepts. Therefore from a practical point of view, it was desirable to make the parameter estimation procedure as uncomplicated as possible in order to minimize computational errors when applying the technique.

3.3.2 Parameters

The parameters selected for use in this study are listed as follows:

Hydrometeorologic Data	Symbol
Index of mean annual precipitation at gauge location (mm)	MAP
Index of mean annual snowfall at gauge location (cm)	MAS
Index of mean annual runoff at gauge location (mm)	MAR

Physiographic Data	Symbol
Drainage area (km^2)	DA
Index of area controlled by lakes and swamps	ACLS
Latitude of gauge location	LAT
Longitude of gauge location	LONG
Length of main channel (km)	LEN
10/85 channel slope (m/m)	SLP
Base Flow Index (dimensionless ratio)	BFI
Regulation Index (0 - non-regulated, 3 - slightly regulated, 6 - moderately regulated, 9 - heavily regulated)	REG
Regional Code (key used in identifying homogeneous regions 1 - Lake Huron Region 2 - West Lake Erie 3 - East Lake Erie	RG

Detailed parameter definition and methodology for derivation is discussed in the following sections.

DA (km^2)

The watershed drainage area was obtained from records published by the Water Survey of Canada. However, in a few cases, it was necessary to modify published drainage areas for a number of reasons (e.g. diversions, more accurate mapping, etc.).

ACLS

An index representing the percentage of the drainage area controlled by lakes and swamps (ACLS) was determined using available topographic mapping for all basins (Scale 1:50,000). A lake or swamp had to have a surface area equal to at least 1% of the drainage area to the outlet of the lake or swamp in order to be considered to have a significant effect on low flows.

LAT

The station latitude expressed in degrees and decimal format was obtained from Water Survey of Canada publications.

LONG

The longitude of the hydrometric station expressed in degrees and decimal format was obtained from records published by the Water Survey of Canada.

SLOPE (m/m)

Channel slopes were determined by creating an elevation distance table which was measured along the main stream of each river system using 1:50,000 scale mapping.

The 10/85 slope (SLP) recommended by the U.S. Geological Survey was calculated by taking the elevation difference at the 10% and 85% points along the channel length.

LEN (km)

The length of the main channel was determined from 1:50,000 scale NTS mapping.

Base Flow Index (BFI) (Dimensionless)

This parameter is an indicator of the hydrogeological effects of the drainage basin soil and geology type and also the retention characteristics (primarily due to lakes and swamps) of the drainage basin. BFI is defined as:

BFI = Total volume of base flow/total volume of runoff

The median values calculated for all Ontario gauging stations having at least 2 years of continuous daily discharge data were plotted at the corresponding drainage basin centroids using 1:600,000 scale base maps for Southern Ontario and isolines drawn. The centroids were located by eye after delineating the drainage area. The isolines map was prepared to help provide estimates of BFI for ungauged basins when applying the regression equations (Regional Flood Frequency, Moin and Shaw, 1986). All estimates of BFI from the isoline maps must be made by first locating the basin centroid and then projecting this point to the closest point on the main channel. The BFI is then interpolated from the isolines at this location on the main channel. A better BFI estimate will be obtained for large basins and in areas where the isolines are very close together, if an average value of BFI, weighted by the area between isolines, is taken over the entire drainage basin. Figure 3.4 reproduces the BFI distribution for the Southwestern West Central region.

RG

Identifying regions by indexing to a common number for sub-region analysis. Cluster analysis of common regression residuals indicated 3 possible homogeneous regions identified as:

1. Lake Huron Region
2. West Lake Erie
3. East Lake Erie

   (see Figure 4.1)

REG (code)

Regulation code (i.e. an assessment of the degree of regulation a stream is determined to have):

0 - non-regulated
3 - some regulation
6 - moderate regulation
9 - heavy regulation

NOTE: Heavily regulated stations were not included in the analysis and simple correlation analysis indicated insignificant levels of correlation with the remaining regulation codes.

MAP (mm)

An index of mean annual precipitation was developed with reference to available publications (MNR, 1984, Environment Canada, 1978). The index of mean annual precipitation is interpolated for each watershed used in the analysis at the gauge location.

MAS (cm)

An index of mean annual snowfall was obtained from available information published by the Ministry of Natural Resources (MNR, 1984). An index map was used to derive the snowfall index for each hydrometric gauge. This index represents total annual snowfall for each watershed. The index was determined at the gauge location.

MAR (mm)

The index of mean annual runoff is expressed as a depth of water averaged over the drainage basin area. The isolines of runoff were obtained from existing information published by Environment Canada and adopted by the Ministry of Natural Resources (Sangal and Kallio, 1977, MNR, 1984). The mean annual runoff index was derived from for each hydrometric station at the gauge location.

3.3.3 Summary of Physiographic and Hydrometeorologic Data

Table 3.6 summarizes the parameters which were determined for each station remaining after screening (see Section 3.2.5). Table 3.7 summarizes the mean, range and other simple statistics of the data base. The selected data contains stations with drainage area varying from 14 to 4000 km^2, with BFI which range from .1 to .8, lengths ranging from 6 to 190 km and slopes ranging from .0003 to .0075 m/m.

A matrix of simple correlation coefficients is presented in Table 3.8. Significant correlation coefficient has a magnitude equal or larger than 0.24. It was found that a few parameters exhibit significant intercorrelation (e.g. REG/LONG; MAP/LAT; MAP/MAS; DA/LEN; DA/YEARS).

Also, latitude was found to be highly correlated with the climatological parameters and longitude was negatively correlated with the climatological parameters. This is a function of the hydrometric network and does not represent a significant hydrologic finding in regard to estimation of low flows.

As one would intuitively expect, drainage area was found to be highly correlated with length. This finding is consistent with other investigations. Generally speaking, equations with drainage area should not likely also contain length as an important parameter, unless the regression coefficients are found to be very stable.

While not shown in the simple correlation matrix, it was also found that the low flows were most highly correlated with drainage area (0.85) followed by length and BFI. Low flows were also found to be negatively correlated with slope, a fact which may be attributed to large base flows generated from large watersheds with smaller slopes.

Table 3.6

SUMMARY OF INDEPENDENT PARAMETERS

STATION NUMBER	RG (code)	MAP (mm)	MAS (cm)	MAR (mm)	DA (km^2)	ACLS (%)	LAT (degree)	LONG (degree)	LEN (km)	SLP (m/m)	YEARS OF RECORD (years)	BFI (index)	REG (code
02FA001	1	910	300	463	927.00	98	44.669	81.253	82.40	.0008900	28	.620	1
02FA002	1	890	350	325	50.50	80	45.036	81.336	8.00	.0035700	10	.500	1
02FB007	2	1000	300	503	181.00	58	44.700	80.950	27.60	.0024500	47	.560	1
02FB010	2	940	300	481	293.00	49	44.569	80.650	33.30	.0034800	28	.550	3
02FC001	1	900	300	449	3960.00	1	44.456	81.327	190.50	.0017300	71	.640	1
02FC011	2	1000	280	404	163.00	1	44.113	81.020	29.50	.0020900	32	.510	1
02FC012	2	1000	280	473	635.00	5	44.099	80.986	97.50	.0023100	14	.420	6
02FC013	2	920	110	255	262.00	30	44.318	81.246	40.00	.0013200	14	.650	3
02FC015	2	900	290	516	663.00	91	44.269	81.269	83.00	.0014400	14	.620	1
02FC016	2	1020	270	375	329.00	36	44.186	80.787	52.30	.0027000	9	.660	1
02FE002	1	960	260	421	1630.00	5	43.887	81.327	76.90	.0012900	32	.410	3
02FE003	2	920	250	386	77.70	9	43.727	80.972	20.20	.0019800	33	.280	6
02FE005	1	960	260	425	528.00	12	43.916	81.264	32.40	.0013200	32	.460	6
02FE007	1	950	260	464	326.00	1	43.854	81.250	50.40	.0017100	18	.400	6
02FE008	1	940	260	432	648.00	2	43.813	81.307	81.70	.0010000	18	.330	1
02FE009	1	900	250	485	373.00	1	43.684	81.544	46.50	.0014800	18	.320	1
02FF002	1	890	190	358	865.00	1	43.072	81.660	100.90	.0010600	38	.370	1
02FF007	1	900	240	397	466.00	1	43.300	81.800	52.50	.0019200	19	.330	1
02GA010	3	900	170	334	1030.00	18	43.191	80.455	145.50	.0009600	42	.490	1
02GA018	2	890	200	342	552.00	1	43.378	80.711	68.60	.0010200	35	.300	1
02GA024	3	840	205	350	59.60	65	43.469	80.519	15.00	.0028700	25	.440	6
02GA029	3	820	180	336	236.00	20	43.548	80.183	42.00	.0043100	23	.560	6
02GA030	3	880	190	137	49.70	1	43.550	80.250	15.10	.0052800	19	.360	3
02GA031	3	820	180	419	44.50	1	43.576	80.110	6.10	.0043900	20	.730	3
02GA033	3	840	200	344	64.80	10	43.663	80.255	11.40	.0034900	29	.460	6
02GA035	2	870	280	370	27.70	1	43.651	80.572	16.00	.0074700	14	.430	1
02GA036	2	890	240	418	17.90	1	43.670	80.597	6.50	.0059700	14	.200	1
02GA037	3	860	200	445	25.10	1	43.439	80.476	6.30	.0049100	13	.320	1
02GA038	2	900	200	399	326.00	1	43.484	80.835	27.00	.0016600	13	.190	1
02GA039	2	840	200	417	272.00	1	43.783	80.639	37.00	.0025000	13	.200	1
02GA040	3	830	200	398	167.00	4	43.639	80.270	22.50	.0037600	12	.390	1
02GB006	3	900	150	379	150.00	1	43.175	80.553	42.50	.0016300	32	.480	3
02GB007	3	900	140	309	360.00	20	43.147	80.155	47.90	.0022100	21	.420	1
02GB008	3	900	150	345	383.00	1	43.126	80.385	26.40	.0013000	24	.550	3
02GB010	3	900	170	301	171.00	1	43.034	79.950	60.00	.0008300	24	.360	6

Table 3.6 (continued)

SUMMARY OF INDEPENDENT PARAMETERS

STATION	RG	MAP	MAS	MAR	DA	ACLS	LAT	LONG	LEN	SLP	YEARS OF	BFI	REG
NUMBER											RECORD		
	(code)	(mm)	(cm)	(mm)	(km^2)	(%)	(degree)	(degree)	(km)	(m/m)	(years)	(index)	(code)
02GC002	2	890	120	369	329.00	1	42.778	81.214	45.50	.0016800	18	.260	6
02GC006	3	900	140	328	363.00	2	42.838	80.510	51.60	.0011900	30	.690	6
02GC007	3	890	120	335	591.00	1	42.685	80.538	85.00	.0010600	30	.750	3
02GC008	3	840	130	374	134.00	1	42.823	80.289	13.00	.0025500	28	.730	6
02GC010	2	900	140	354	342.00	1	42.861	80.719	40.50	.0012000	25	.520	6
02GC012	3	890	140	419	51.30	1	42.854	80.328	12.00	.0017200	21	.800	3
02GC013	3	900	110	401	75.90	1	42.628	80.472	19.00	.0028000	20	.480	6
02GC015	2	900	120	438	105.00	1	42.756	80.807	25.50	.0017500	22	.670	3
02GC017	3	900	150	390	93.20	1	42.965	80.543	10.50	.0014300	21	.500	1
02GC018	2	890	110	395	287.00	1	42.746	81.044	31.50	.0013900	21	.280	1
02GC021	3	900	110	250	68.40	1	42.674	80.600	22.50	.0023600	19	.750	3
02GC026	3	900	100	248	676.00	1	42.708	80.839	82.00	.0007400	10	.620	6
02GD001	2	900	160	336	1340.00	10	42.973	81.210	88.80	.0012500	70	.510	1
02GD004	2	900	200	369	306.00	1	43.059	80.988	37.90	.0021300	37	.400	6
02GD009	2	900	222	350	140.00	100	43.264	81.080	32.00	.0017000	34	.440	3
02GD011	2	890	180	315	93.20	1	43.128	80.768	12.80	.0018300	32	.360	6
02GD012	2	890	180	347	254.00	100	43.144	80.751	36.80	.0015400	33	.410	1
02GD015	2	900	210	386	1340.00	10	43.149	81.192	66.50	.0010700	32	.370	6
02GD018	2	890	230	437	144.00	4	43.345	81.116	24.60	.0012300	21	.340	6
02GD020	2	900	180	315	108.00	1	42.994	81.117	32.50	.0025200	20	.360	1
02GE005	2	890	150	316	146.00	1	42.934	81.351	37.20	.0009500	20	.290	1
02GG002	2	840	140	320	730.00	1	42.830	81.853	79.00	.0008400	37	.420	1
02GG004	1	780	140	288	609.00	1	42.764	82.342	89.50	.0003600	19	.270	1
02GG005	1	890	160	356	172.00	1	42.960	81.628	81.00	.0008100	19	.470	1
02GG006	1	800	140	299	267.00	1	42.906	82.120	36.50	.0009400	19	.200	1
02GG007	2	800	120	312	1240.00	1	42.594	82.109	57.50	.0003400	16	.370	1
02GH001	2	810	90	413	14.20	11	42.046	83.575	8.10	.0044500	11	.390	1
02GH002	2	810	110	286	125.00	1	42.232	82.094	20.00	.0009900	14	.150	1
02GH003	2	790	105	200	159.00	25	42.159	83.018	22.00	.0004500	9	.100	1
02HA006	3	800	120	302	293.00	1	43.134	79.383	80.00	.0005500	28	.150	1

Table 3.7

Simple Statistics of Independent Parameters

Parameter	Mean	Std Dev	Skewness	S.E. Skew	Range	Minimum	Maximum	N
RG (code)	2.12	.72	-.19	.30	2.00	1	3	65
MAP (mm)	888.62	50.37	.13	.30	240.00	780	1020	65
MAS (cm)	189.72	64.09	.46	.30	260.00	90	350	65
MAR (mm)	367.74	71.28	-.45	.30	379.00	137	516	65
DA (km^2)	414.00	571.57	4.15	.30	3945.80	14.20	3960.00	65
ACLS (percent)	14.05	26.86	2.32	.30	99.00	1	100	65
LAT (degrees)	43.34	.63	.54	.30	2.99	42.046	45.036	65
LONG (degrees)	80.99	.70	1.11	.30	4.19	79.383	83.575	65
LEN (km)	45.89	34.55	1.63	.30	184.40	6.10	190.50	65
SLP 10/85 (m/m)	.00	.00	1.69	.30	7.130E-03	.0003400	.0074700	65
YEARS OF RECORD (years)	24.37	12.00	1.82	.30	62.00	9	71	65
BFI (index)	.44	.16	.22	.30	.70	.100	.800	65
REG (code)	2.75	2.16	.69	.30	5.00	1	6	65

Table 3.8

Correlation Matrix of Independent Parameters

	RG (code)	MAP (mm)	MAS (cm)	MAR (mm)	DA (km^2)	ACLS (%)	LAT (degree)	LONG (degree)	LEN (km)	SLP (m/m)	RECORD LENGTH (years)	BFI (index)	REG (code)
RG	1	-0.2013	-0.4758	-0.3159	-0.3686	-0.1312	-0.3204	-0.645	-0.3813	0.2605	-0.0989	0.312	0.3253
MAP	-0.2013	1	0.5494	0.4402	0.1076	0.1472	0.5414	-0.1982	0.1465	-0.0305	0.1935	0.3237	0.142
MAS	-0.4758	0.5494	1	0.5727	0.2451	0.4229	0.8763	-0.0534	0.1792	0.2707	0.1821	0.0672	-0.0721
MAR	-0.3159	0.4402	0.5727	1	0.1896	0.181	0.4763	-0.0157	0.1377	0.0586	0.1592	0.2004	0.0009
DA	-0.3686	0.1076	0.2451	0.1896	1	-0.0509	0.2131	0.1872	0.8247	-0.2831	0.5843	0.1057	-0.137
ACLS	-0.1312	0.1472	0.4229	0.181	-0.0509	1	0.4596	0.0308	-0.0468	0.0569	0.0364	0.1813	-0.1453
LAT	-0.3204	0.5414	0.8763	0.4763	0.2131	0.4596	1	-0.2246	0.1635	0.2661	0.1408	0.2208	-0.0731
LONG	-0.645	-0.1982	-0.0534	-0.0157	0.1872	0.0308	-0.2246	1	0.1475	-0.2637	-0.1163	-0.352	-0.3443
LEN	-0.3813	0.1465	0.1792	0.1377	0.8247	-0.0468	0.1635	0.1475	1	-0.4416	0.4544	0.0512	-0.1748
SLP	0.2605	-0.0305	0.2707	0.0586	-0.2831	0.0569	0.2661	-0.2637	-0.4416	1	-0.1779	0.1869	0.056
YEARS	-0.0989	0.1935	0.1821	0.1592	0.5843	0.0364	0.1408	-0.1163	0.4544	-0.1779	1	0.1857	0.0375
BFI	0.312	0.3237	0.0672	0.2004	0.1057	0.1813	0.2208	-0.352	0.0512	0.1869	0.1857	1	0.2016
REG	0.3253	0.142	-0.0721	0.0009	-0.137	-0.1453	-0.0731	-0.3443	-0.1748	0.056	0.0375	0.2016	1

4.0 REGIONALIZATION OF LOW FLOW CHARACTERISTICS

4.1 General

Four alternative methods of regionalizing extreme value low flows and flow duration values at the 95% level (Q_{95}) were examined. They are; Multiple Linear Regression (Section 4.2), Index method (Section 4.3), Area Proration mapping of unit flow values (Section 4.4), and Isolines of unit low flows (Section 4.5). Emphasis was placed on determining $7Q_{20}$ and Q_{95} as these flows were identified to be the key low flow statistic required byr M.O.E.

4.2 Regression

4.2.1 General

Multiple linear regression equations take the following general form:

$$Y = a_0 + a_1Y_1 + a_2Y_2 + \ldots\ldots + a_nY_n \tag{4.1}$$

where Y = the dependent variable (e.g. $7Q_{20}$)

$Y_1, Y_2 \ldots Y_n$ = the independent variables (e.g. physiographic and hydrometeorologic watereshed characteristics)

$a_0, a_1 \ldots a_n$ = regression coefficients

In order to obtain a more accurate regression equation, it is sometimes necessary to transform the data by taking logarithms, square roots, cubes, etc. The transformations considered for this investigation are discussed in Section 4.2.3.

A number of regression procedures are available, including development of all possible equations, forward selection, backward selection, stagewise regression and stepwise regression. The stepwise regression procedure is generally recommended for use in practical applications (Draper and Smith, 1981) and was, therefore, adopted for the purposes of this investigation.

4.2.2 Methodology

The regression equations were developed utilizing the stepwise multiple linear regression procedure available in the Statistical Package for the Social Sciences (SPSS) (Nie, 1975). More specifically, the regression subprogram has been used and has the following special features:

1. Various procedures for selecting variables, including forward selection, backward elimination and the stepwise selection feature, which is really a combination of backward and forward procedures, was adopted for this investigation as it is the most commonly used procedure.
2. Variable selection - all independent variables can be stored and then only those variables desired for a particular analysis called up and used according to the desired form of the equation
3. Combination of variables - variable transformation and new variables may be computed from existing variables
4. Transformations - the variables may be transformed (e.g. square root, logarithmic, reciprocal, etc.) in order to more nearly linearize the relationships
5. Calculation of statistics - The SPSS regression package allows calculation of numerous regression coefficients, statistics and residual statistics (difference between observed and calculated values). Also possible are scatter plots of residuals and statistical tests for residual analysis, etc.

The regression constant and regression coefficients are determined in order to minimize the sum of the squared residuals. The residuals are the difference between the observed, dependent variable and the prediction by the regression equation. The SPSS program automatically includes those independent variables which meet the 95% confidence level based on the computed value of the F statistic. Only those variables which meet the specified level at any given step are retained in the regression equation and all those variables which fall below the specified level are deleted from the regression equation.

Preliminary regression equations were developed in order to predict the $7Q_2$, $7Q_{20}$, $7Q_{50}$, $3Q_2$, $3Q_{20}$, $3Q_{50}$, $30Q_2$, $30Q_{20}$, $30Q_{50}$ and Q_{95} low flows as a function of basin physiographic and hydrometeorologic parameters. Untransformed parameters which entered into the equation in order of significance are drainage area, base flow index, slope and mean annual precipitation or snowfall. The resulting equation for $7Q_{20}$ and Q_{95} had R^2 values of .84, .88, and a standard error of 0.50 and 0.67 respectively (see Table 4.1).

4.2.3 Transformations

Several methods of transforming the parameters to normalize the distribution were considered, including:

i) LOG_{10}
ii) LOG NORMAL
iii) 10^X
iv) e^X
v) ROOTS
vi) SQUARES)
vii) CUBICS)POWERS
viii) COMBINATIONS

Logarithmic transformations were found to be unsuccessful in the present investigation.

Since the logarithmetic transformations were unsuccessful, exponents (e^X, 10^X) were considered next. These transformations increased skewness and no improvement was found in the regression equation.

TABLE 4.1

Summary of Regression Analysis

Untransformed Variables

$$y = a_0 + a_1\ DA + a_2\ BFI + a_3\ SLP + a_4\ MAP + a_5\ MAS$$

Dependent Parameter	Independent Parameters								
	a_0	a_1	a_2	a_3	a_4	a_5	N	SE	R^2
$7Q_2$	-1.34	2.44×10^{-3}	1.87	194.73		-1.65×10^{-3}	65	.60	.89
$7Q_{20}$	0.07	1.61×10^{-3}	1.35	127.43	-1.42×10^{-3}		65	.50	.84
$7Q_{50}$	0.20	1.47×10^{-3}	1.25	118.74	-1.48×10^{-3}		65	.50	.81
$3Q_2$	-.129	2.40×10^{-3}	1.74	191.83		-1.61×10^{-3}	65	.58	.89
$3Q_{20}$	0.08	1.52×10^{-3}	1.22	123.66	-1.36×10^{-3}		65	.47	.84
$3Q_{50}$	0.17	1.36×10^{-3}	1.17	113.79	-1.36×10^{-3}		65	.46	.81
$30Q_2$	-1.50	2.81×10^{-3}	2.38	181.17		-1.83×10^{-3}	62	.67	.90
$30Q_{20}$	-1.08	1.88×10^{-3}	1.66	150.47		-1.64×10^{-3}	62	.59	.84
$30Q_{50}$	1.03	1.77×10^{-3}	1.56	147.08		-1.63×10^{-3}	62	.59	.82
Q_{95}	-1.43	2.55×10^{-3}	2.16	187.81		-1.69×10^{-3}	65	.67	.88

Plotting of each independent parameter against the dependent parameter suggested that an exponential conversion of some of the independent parameters would provide a better relationship.

The literature review also revealed several forms of prediction equations using the square root of selected independent parameters, and hence this type of transformation was attempted. The results are tabulated in Table 4.2. The R^2 values are lower and there are higher standard errors of SE values when compared to equations developed using the untransformed parameters.

Exponents ranging from 1/3 to 3 transforms were used for DA, BFI, and LEN. The best general improvement was found for DA^3, BFI^2 and LEN^2.

Recent literature also suggested combinations of independent parameters. For example, it was suggested that:

$$\left[\frac{LEN}{(SLP)^{1/2}}\right]^{1/2} \text{ and } \left[\frac{BFI}{(LEN/(SLP)^{1/2}}\right]^{1/2} \qquad (4.5)$$

would provide a combination parameter which would increase the fit of the regression equation. However, it was found that these combination transforms did not significantly improve the regression equations and could possibly result in spurious results when combined in this fashion with drainage area and/or Base Flow Index.

Table 4.3 summarizes the final transformed and untransformed simple correlations between the independent variables and using various transformations on the independent variables. With reference to Table 4.3, it is evident that DA^3, $LENGTH^2$ and BFI^2 have correlation coefficients of 0.95, 0.88 and 0.31 compared to the correlation coefficients of 0.84, .68 and .31 for their untransformed counterparts.

TABLE 4.2

Summary of Regression Analysis

Common Square Root Transform

$$y = a_0 + a_1 \, DA^{1/2} + a_2 \, BFI^{1/2} + a_3 \, LEN^{1/2} + a_4 \, MAP^{1/2} + a_5 \, LOG \, MAS$$

Dependent Parameter	Independent Parameters								
	a_0	a_1	a_2	a_3	a_4	a_5	N	SE	R^2
$7Q_2$	3.46	0.14	3.94	-0.11	-0.35	1.41	65	1.03	.68
$7Q_{20}$	2.95	0.75	2.74		-0.28	1.21	65	.78	.60
$7Q_{50}$	2.27	0.07	2.33		-0.16		65	.75	.58
$3Q_2$	3.51	0.13	3.73	-0.10	-0.34	1.39	65	1.00	.68
$3Q_{20}$	2.86	0.07	2.52		-0.27	1.71	65	.74	.60
$3Q_{50}$	2.78	0.06	2.30		-0.25	1.09	65	.69	.58
$30Q_2$	3.32	0.14	5.16		-0.38	1.28	62	1.14	.71
$30Q_{20}$	2.47	0.09	3.51		-0.20		62	.90	.62
$30Q_{50}$	2.68	0.09	3.33		-0.20		62	.87	.60
Q_{95}	3.36	0.12	4.43		-0.38	1.55	65	1.10	.67

Table 4.3

Correlation Matrix of Dependent and Independent Parameters

	RG	MAP (mm)	MAS (cm)	MAR (mm)	DA (km^2)	ACLS (%)	LAT (degree)	LONG (degree)	LEN (km)	SLP (m/m)	RECORD (years)	BFI (index)	REG (code)
RG	1.00	-0.20	-0.48	-0.32	-0.37	-0.13	-0.32	-0.65	-0.38	0.26	-0.10	0.31	0.33
MAP	-0.20	1.00	0.55	0.44	0.11	0.15	0.54	-0.20	0.15	-0.03	0.19	0.32	0.14
MAS	-0.48	0.55	1.00	0.57	0.25	0.42	0.88	-0.05	0.18	0.27	0.18	0.07	-0.07
MAR	-0.32	0.44	0.57	1.00	0.19	0.18	0.48	-0.02	0.14	0.06	0.16	0.20	0.00
DA	-0.37	0.11	0.25	0.19	1.00	-0.05	0.21	0.19	0.82	-0.28	0.58	0.11	-0.14
ACLS	-0.13	0.15	0.42	0.18	-0.05	1.00	0.46	0.03	-0.05	0.06	0.04	0.18	-0.15
LAT	-0.32	0.54	0.88	0.48	0.21	0.46	1.00	-0.22	0.16	0.27	0.14	0.22	-0.07
LONG	-0.65	-0.20	-0.05	-0.02	0.19	0.03	-0.22	1.00	0.15	-0.26	-0.12	-0.35	-0.34
LEN	-0.38	0.15	0.18	0.14	0.82	-0.05	0.16	0.15	1.00	-0.44	0.45	0.05	-0.17
SLP	0.26	-0.03	0.27	0.06	-0.28	0.06	0.27	-0.26	-0.44	1.00	-0.18	0.19	0.06
RECORD	-0.10	0.19	0.18	0.16	0.58	0.04	0.14	-0.12	0.45	-0.18	1.00	0.19	0.04
BFI	0.31	0.32	0.07	0.20	0.11	0.18	0.22	-0.35	0.05	0.19	0.19	1.00	0.20
REG	0.33	0.14	-0.07	0.00	-0.14	-0.15	-0.07	-0.34	-0.17	0.06	0.04	0.20	1.00
7Q2	-0.17	0.11	0.20	0.15	0.89	-0.01	0.24	0.05	0.70	-0.11	0.57	0.32	-0.06
7Q20	-0.16	0.10	0.18	0.13	0.84	-0.02	0.24	0.05	0.68	-0.09	0.50	0.31	-0.07
7Q50	-0.15	0.09	0.18	0.12	0.83	-0.02	0.24	0.05	0.67	-0.09	0.48	0.31	-0.07
3Q2	-0.17	0.11	0.20	0.15	0.89	-0.01	0.24	0.05	0.70	-0.11	0.57	0.31	-0.07
3Q20	-0.16	0.09	0.18	0.13	0.84	-0.02	0.24	0.05	0.68	-0.09	0.50	0.30	-0.08
3Q50	-0.15	0.09	0.18	0.13	0.83	-0.02	0.24	0.05	0.67	-0.09	0.47	0.30	-0.07
30Q2	-0.16	0.13	0.19	0.15	0.89	-0.01	0.23	0.04	0.71	-0.13	0.56	0.34	-0.04
30Q20	-0.13	0.11	0.16	0.11	0.84	-0.03	0.22	0.03	0.68	-0.11	0.49	0.34	-0.03
30Q50	-0.12	0.10	0.15	0.11	0.82	-0.03	0.22	0.03	0.67	-0.10	0.47	0.34	-0.04
Q95	-0.15	0.12	0.18	0.14	0.87	-0.01	0.24	0.04	0.71	-0.12	0.53	0.34	-0.05
DA^3	-0.22	0.04	0.23	0.15	0.84	-0.07	0.22	0.07	0.61	-0.04	0.53	0.15	-0.11
BFI^2	0.34	0.24	-0.02	0.15	0.08	0.14	0.15	-0.34	0.03	0.14	0.14	0.98	0.17
LEN^2	-0.33	0.08	0.22	0.16	0.90	-0.06	0.21	0.13	0.92	-0.26	0.53	0.13	-0.17
LOG(MAR)	-0.45	0.53	0.99	0.56	0.23	0.38	0.85	-0.11	0.17	0.26	0.22	0.04	-0.04
LOG(MAS)	-0.30	0.40	0.51	0.98	0.18	0.15	0.41	-0.02	0.14	0.01	0.18	0.19	0.01

	7Q2 (m^3/s)	7Q20 (m^3/s)	7Q50 (m^3/s)	3Q2 (m^3/s)	3Q20 (m^3/s)	3Q50 (m^3/s)	30Q2 (m^3/s)	30Q20 (m^3/s)	30Q50 (m^3/s)	Q95 (m^3/s)	D.A.^3	BFI^2	LEN^2	LOG(MAR)	LOG(MAS)
RG	-0.17	-0.16	-0.15	-0.17	-0.16	-0.15	-0.16	-0.13	-0.12	-0.15	-0.22	0.34	-0.33	-0.45	-0.30
MAP	0.11	0.10	0.09	0.11	0.09	0.09	0.13	0.11	0.10	0.12	0.04	0.24	0.08	0.53	0.40
MAS	0.20	0.18	0.18	0.20	0.18	0.18	0.19	0.16	0.15	0.18	0.23	-0.02	0.22	0.99	0.51
MAR	0.15	0.13	0.12	0.15	0.13	0.13	0.15	0.11	0.11	0.14	0.15	0.15	0.16	0.56	0.98
DA	0.89	0.84	0.83	0.89	0.84	0.83	0.89	0.84	0.82	0.87	0.84	0.08	0.90	0.23	0.18
ACLS	-0.01	-0.02	-0.02	-0.01	-0.02	-0.02	-0.01	-0.03	-0.03	-0.01	-0.07	0.14	-0.06	0.38	0.15
LAT	0.24	0.24	0.24	0.24	0.24	0.24	0.23	0.22	0.22	0.24	0.22	0.15	0.21	0.85	0.41
LONG	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.03	0.03	0.04	0.07	-0.34	0.13	-0.11	-0.02
LEN	0.70	0.68	0.67	0.70	0.68	0.67	0.71	0.68	0.67	0.71	0.61	0.03	0.92	0.17	0.14
SLP	-0.11	-0.09	-0.09	-0.11	-0.09	-0.09	-0.13	-0.11	-0.10	-0.12	-0.04	0.14	-0.26	0.26	0.01
RECORD	0.57	0.50	0.48	0.57	0.50	0.47	0.56	0.49	0.47	0.53	0.53	0.14	0.53	0.22	0.18
BFI	0.32	0.31	0.31	0.31	0.30	0.30	0.34	0.34	0.34	0.34	0.15	0.98	0.13	0.04	0.19
REG	-0.06	-0.07	-0.07	-0.07	-0.08	-0.07	-0.04	-0.03	-0.04	-0.05	-0.11	0.17	-0.17	-0.04	0.01
7Q2	1.00	0.99	0.98	1.00	0.99	0.98	1.00	0.99	0.98	1.00	0.95	0.31	0.89	0.16	0.13
7Q20	0.99	1.00	1.00	0.99	1.00	1.00	0.99	1.00	1.00	0.99	0.95	0.31	0.88	0.14	0.11
7Q50	0.98	1.00	1.00	0.99	1.00	1.00	0.98	1.00	1.00	0.99	0.95	0.31	0.88	0.14	0.10
3Q2	1.00	0.99	0.99	1.00	0.99	0.98	1.00	0.99	0.98	1.00	0.95	0.31	0.89	0.16	0.13
3Q20	0.99	1.00	1.00	0.99	1.00	1.00	0.99	0.99	0.99	0.99	0.96	0.30	0.89	0.15	0.11
3Q50	0.98	1.00	1.00	0.98	1.00	1.00	0.98	0.99	0.99	0.99	0.95	0.31	0.88	0.14	0.11
30Q2	1.00	0.99	0.98	1.00	0.99	0.98	1.00	0.99	0.98	1.00	0.94	0.33	0.89	0.15	0.13
30Q20	0.99	1.00	1.00	0.99	0.99	0.99	0.99	1.00	1.00	1.00	0.94	0.34	0.88	0.12	0.10
30Q50	0.98	1.00	1.00	0.98	0.99	0.99	0.98	1.00	1.00	0.99	0.94	0.34	0.87	0.11	0.09
Q95	1.00	0.99	0.99	1.00	0.99	0.99	1.00	1.00	0.99	1.00	0.94	0.33	0.89	0.15	0.12
DA^3	0.95	0.95	0.95	0.95	0.96	0.95	0.94	0.94	0.94	0.94	1.00	0.15	0.86	0.20	0.14
BFI^2	0.31	0.31	0.31	0.31	0.30	0.31	0.33	0.34	0.34	0.33	0.15	1.00	0.12	-0.05	0.14
LEN^2	0.89	0.88	0.88	0.89	0.89	0.88	0.89	0.88	0.87	0.89	0.86	0.12	1.00	0.20	0.15
LOG(MAR)	0.16	0.14	0.14	0.16	0.15	0.14	0.15	0.12	0.11	0.15	0.20	-0.05	0.20	1.00	0.50
LOG(MAS)	0.13	0.11	0.10	0.13	0.11	0.11	0.13	0.10	0.09	0.12	0.14	0.14	0.15	0.50	1.00

4.2.4 Regional Regression Results

The form of the equation of the final regressions, the corresponding coefficients, etc. are shown in Table 4.4. (The square root of the period of record was used as a weighting factor for each station.)

It should be noted that DA^3, BFI^2, and LEN^2 entered sequentially into the equation. The length parameter was not significant for 30-day average low flow values with a recurrence interval greater than 2 years. The constants of the equation are all relatively small. This is due to the large values created by transforming the gauged data to exponent values of cubed and squared (e.g. mean DA is 414 km^2, and the cubic transform is 7.1×10^7). Hence the small coefficients are statistically significant due to the large independent parameters with which they are associated. The coefficients decrease with increased recurrence interval and increase with the increase of the n-day flows analysed.

4.2.5 Sub-regions

It is possible that sub-regions could be identified for which local regional equations may result in a better fit to the data since any extraneous factors affecting the low flow which are not included in the regression would be nearly constant in the region. In other words, regionalization in this context is an attempt to account for neglected factors, that is hydrologic factors which may be common to a region. A different set of prediction equations is developed for identified sub-regions which indirectly takes into account local low flow characteristics.

A preliminary regression equation was developed covering all stations (i.e. no regions initially, see Table 4.4). An analysis of residuals was then undertaken by plotting the standardized residuals on a colour coded map of the hydrometric gauge locations (see

TABLE 4.4

Summary of Regression Analysis

$$y = a_0 + a_1\ DA^3 + a_2\ BFI^2 + a_3\ LEN^2 + a_4\ LOG\ MAR + a_5\ LOG\ MAS$$

Dependent Parameter	Independent Parameters								
	a_0	a_1	a_2	a_3	a_4	a_5	N	SE	R^2
$7Q_2$	-.190	$1.24x10^{-10}$	1.67	$8.35x10^{-5}$			65	.31	.96
$7Q_{20}$	-.166	$9.03x10^{-11}$	1.10	$4.67x10^{-5}$			65	.21	.96
$7Q_{50}$	-.160	$8.54x10^{-11}$	1.02	$3.92x10^{-5}$			65	.21	.95
$3Q_2$	-.183	$1.21x10^{-10}$	1.55	$7.81x10^{-5}$			65	.28	.96
$3Q_{20}$	-.158	$8.57x10^{-11}$	.99	$4.30x10^{-5}$			65	.19	.96
$3Q_{50}$	-.150	$7.92x10^{-11}$	.91	$3.64x10^{-5}$			65	.19	.95
$30Q_2$	-.233	$1.29x10^{-10}$	2.12	$1.12x10^{-4}$			62	.41	.94
$30Q_{20}$	-.227	$9.58x10^{-11}$	1.52				62	.29	.94
$30Q_{50}$	-.078	$1.25x10^{-10}$	1.44				62	.33	.92
Q_{95}	-.230	$1.26x10^{-10}$	1.98	$8.97x10^{-5}$			65	.35	.95

Figure 4.1). From an analysis of the plotted residuals, it was possible to identify a cluster of residuals which indicated that the preliminary regression equation consistently overestimated the low flow estimates in the streams draining to Lake Huron and East Lake Erie. Similarly, a cluster of residuals around West Lake Erie consistently underestimated the low flows.

Subsequent to the preliminary identification of low flow regions, separate prediction equations were formulated for each of the three sub-regions referred to above, that is namely:

1. Lake Huron
2. West Lake Erie
3. East Lake Erie

Refer to Figure 4.1 for identification of boundaries locating each of these regions.

The standard error of estimate of the prediction equations for each region are considerably better than the standard error of estimate for the prediction equation developed for the Southwestern West Central Region as a whole (see Tables 4.4 and 4.5 for comparison of standard error of estimates of the region and sub-regions prediction equations).

A regional set of regression equations were developed for the three regions indicated earlier (see Figure 4.1) for which the coefficients and equation statistics are summarized in Table 4.5.

In the Lake Huron region only DA^3 and BFI^2 entered into most of the equations, while in some cases DA^3 was the only significant parameter. The West Lake Erie region had Log (MAR) enter into 5 of the extreme value equations, BFI^2 and LEN^2 remained as significant parameters and DA^3 did not appear to be significant except for short recurrence interval low flows. Alternately Log (MAS) entered into the regression equations for the East Lake Erie region while

TABLE 4.5a

Summary of Regression Analysis

Lake Huron Region

$$y = a_0 + s_1\ DA^3 + a_2\ BFI^2 + a_3\ LEN^2 + a_4\ LOG\ MAR + a_5\ LOG\ MAS$$

Dependent Parameter	Independent Parameters								
	a_0	a_1	a_2	a_3	a_4	a_5	N	SE	R^2
$7Q_2$	-.17	$1.65x10^{-10}$	2.67				13	.31	.996
$7Q_{20}$	-.12	$1.16x10^{-10}$	1.27				13	.14	.996
$7Q_{50}$	.049	$1.12x10^{-10}$					13	.21	.99
$3Q_2$	-.166	$1.59x10^{-10}$	2.50				13	.18	.997
$3Q_{20}$	-.12	$1.09x10^{-10}$	1.16				13	.19	.96
$3Q_{50}$	.04	$1.04x10^{-10}$					13	.19	.99
$30Q_2$	-.18	$1.84x10^{-10}$	3.35				13	.26	.995
$30Q_{20}$	-.12	$1.32x10^{-10}$	1.47				13	.14	.997
$30Q_{50}$	-.12	$1.26x10^{-10}$	1.29				13	.17	.995
Q_{95}	-.19	$1.71x10^{-10}$	2.96				13	.20	.996

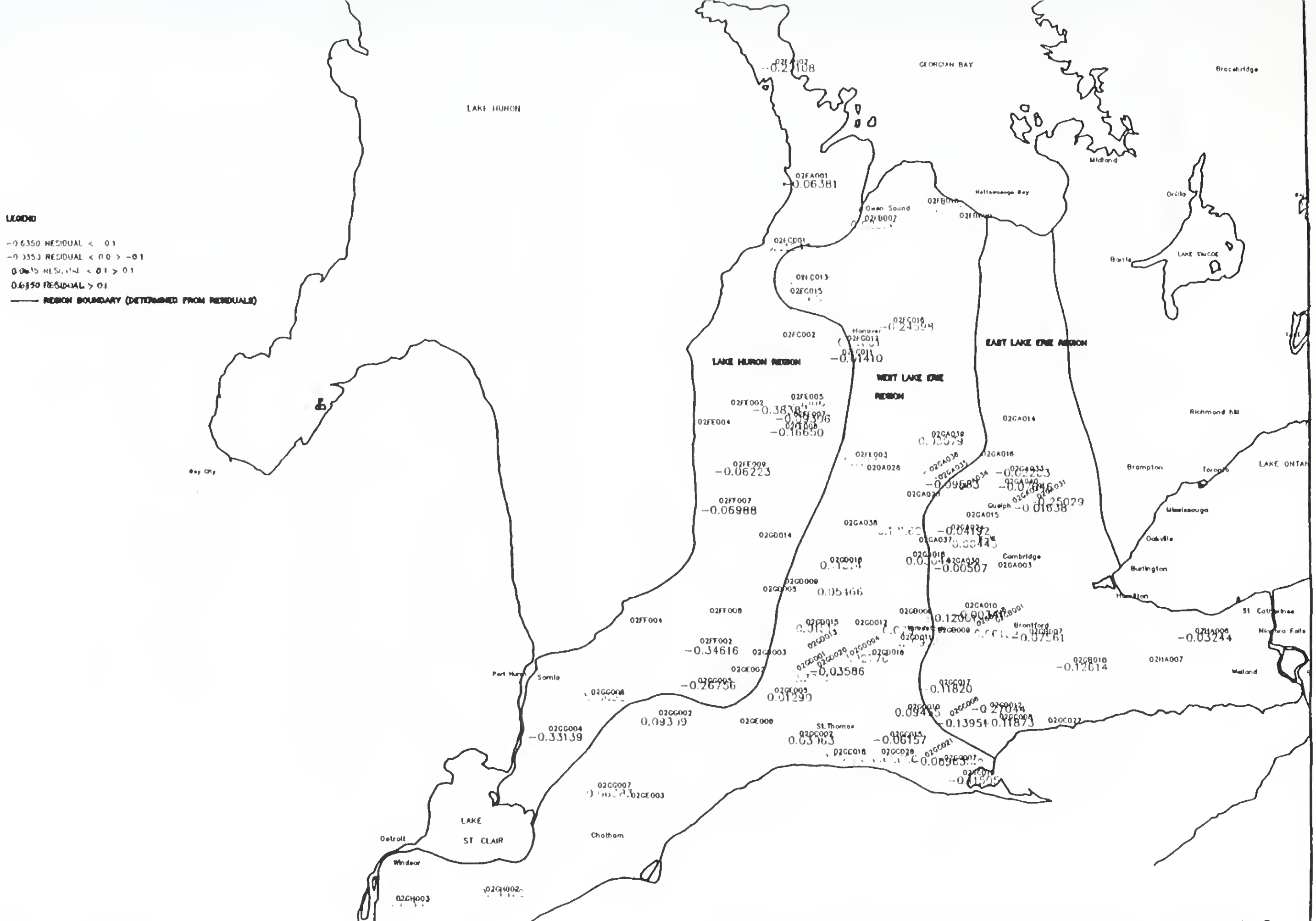
TABLE 4.5c

Summary of Regression Analysis

East Lake Erie

$$y = a_0 + s_1\,DA^3 + a_2\,BFI^2 + a_3\,LEN^2 + a_4\,LOG\,MAR + a_5\,LOG\,MAS$$

Dependent Parameter	Independent Parameters								
	a_0	a_1	a_2	a_3	a_4	a_5	N	SE	R^2
$7Q_2$	-.12	2.048×10^{-9}	1.44				21	.34	.75
$7Q_{20}$	3.89	1.22×10^{-9}				-1.71	21	.25	.68
$7Q_{50}$	3.83	1.04×10^{-9}				-1.69	21	.25	.63
$3Q_2$	-.12	1.93×10^{-9}	1.34				21	.31	.75
$3Q_{20}$	3.56	1.11×10^{-9}				-1.57	21	.24	.66
$3Q_{50}$	3.51	9.34×10^{-10}	1.15			-1.55	21	.23	.61
$30Q_2$	-.09	8.14×10^{-9}	1.16				21	.18	.95
$30Q_{20}$	-.105	6.51×10^{-9}	.76				21	.10	.97
$30Q_{50}$	-.10	6.30×10^{-9}	.70				21	.09	.98
Q_{95}	7.74	2.11×10^{-9}				-3.37	21	.49	.64



MAP OF REGIONS FROM RESIDUAL ANALYSIS

FIGURE 4.1

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in some cases BFI^2 did not appear significant. In the Lake Huron region DA^3 and LEN^2 become significantly intercorrelated and hence LEN^2 is omitted from the resulting equation. Stream length LEN^2 appears to explain the variation of low flow values better than DA^3 and hence due to significant intercorrelation DA^3 is omitted from the resulting equations for West Lake Erie region. Base flow index BFI^2 parameter does not vary areally within the East Lake Erie region and hence does not explain the low flow value variation in this region significantly.

Although R and SE values improved, they must be examined in respect to the diminished samples from which they were determined. Constants for equations for which BFI^2 or DA^3 were not included tend to be large positive values when compared to equations with these parameters.

4.2.6 Summary of Regression Analysis

- Drainage Area (DA), Base Flow Index (BFI) and Length (LEN) were found to be the main physiographic parameters which affect low flows.
- Mean Annual Snowfall (MAS) and Mean Annual Runoff (MAR) entered prediction equations for sub-regions. Figure 4.1 depicts the sub-regional boundaries (Lake Huron, West Lake Erie and East Lake Erie)
- Table 4.4 summarizes the recommended regression equations for six average d-day flow for various recurrence interval low flows
- Transforming drainage area by exponent 3, BFI and length by exponent 2 and by taking the Log_{10} of MAR and MAS produced better regression results
- Table 4.5 summarizes the regression equations for the three sub-regions.

4.3 Index Method

The previous analysis identified possible sub-regions and determined that drainage area (DA) is highly correlated to low flows.

Therefore, a graph of $7Q_2$ as a function of DA was plotted (see Figure 4.2). This relationship had an R^2 of .48 and SE of .39 for a sample size of 64 stations. Figure 4.3 illustrates values of Q_{95} plotted against drainage area.

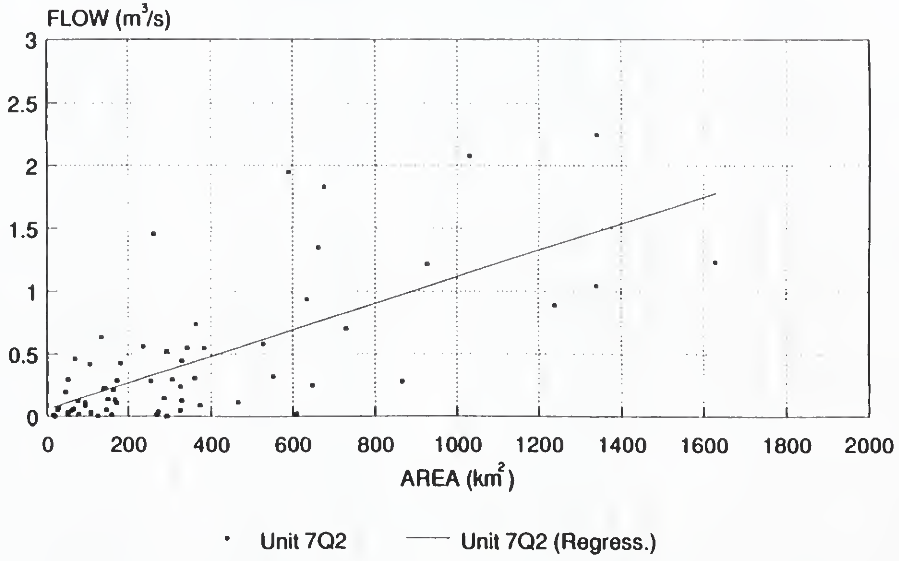
Three stations; 02FC013, North Saugeen River near Paisley; 02GC007, Big Creek near Walsingham; and 02GC026, Big Otter Creek near Colton, exhibit abnormally high low flows. Subsequent investigation identified that these stations have significantly higher BFI values. Hence some areas require more than contributing drainage area for good estimates of low flow characteristics (see Section 4.5).

Further subdivided into sub-regions, Figure 4.4 illustrates how the $7Q_2$ flow varies per sub-region as a function of DA. The subregional analysis indicates a minimum requirement of drainage area of 30 to 150 km^2 for non-zero $7Q_2$ values in Lake Huron and East Lake Erie regions.

Previous studies have shown interrelationships between n day and 10 day average low flows. Further to this, the ratio of various n day flows with y year recurrence to 7Qy was determined. The results of these analyses are depicted on Figures 4.5 and 4.6.

To use this method knowing the drainage area, the $7Q_2$ flow could be determined from Figure 4.2 or Figure 4.4. If another nQy flow is required, it can be estimated by using Figure 4.5 and/or Figure 4.6 to determine the appropriate flow ratio as a function of $7Q_2$. The estimating error for $7Q_2$ and the errors associated with the index ratio suggest that this method would not provide the same level of

7Q2 AS A FUNCTION OF DRAINAGE AREA
Three Regions Combined



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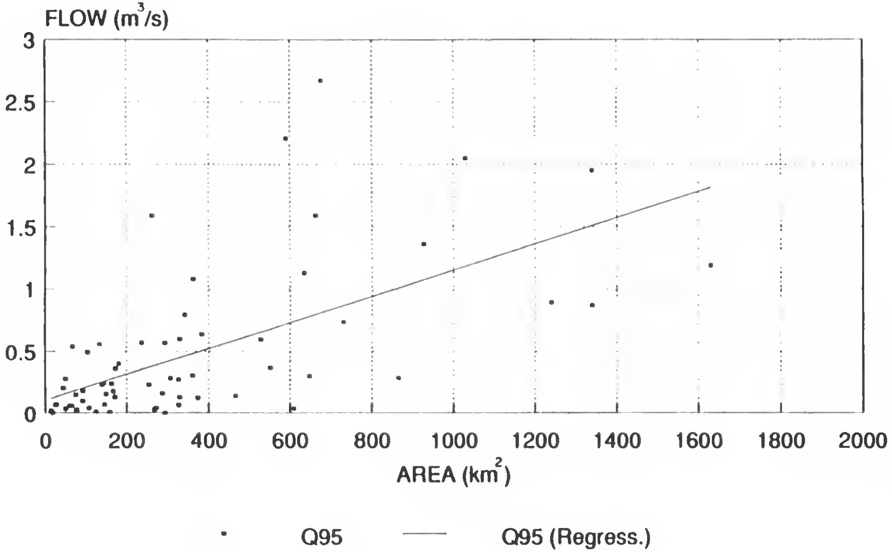
7 Q2 AS A FUNCTION OF DRAINAGE AREA.
(THREE REGIONS COMBINED)

FIGURE 4.2

Q95 AS A FUNCTION OF DRAINAGE AREA
Three Regions Combined



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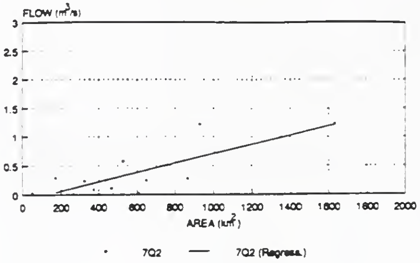
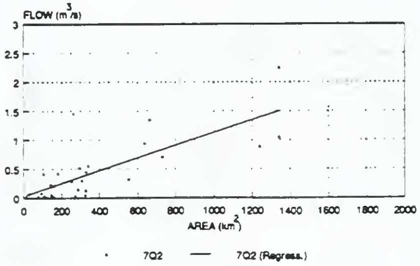
Q 95 AS A FUNCTION OF
DRAINAGE AREA
(THREE REGIONS COMBINED)

FIGURE 4.3

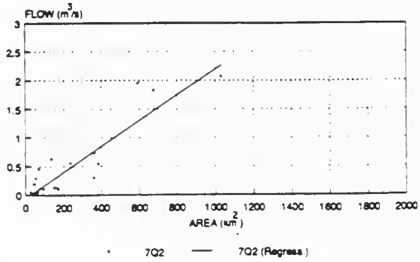
7Q2 AS A FUNCTION OF DRAINAGE AREA
Lake Huron Region



7Q2 AS A FUNCTION OF DRAINAGE AREA
West Lake Erie Region



7Q2 AS A FUNCTION OF DRAINAGE AREA
East Lake Erie Region



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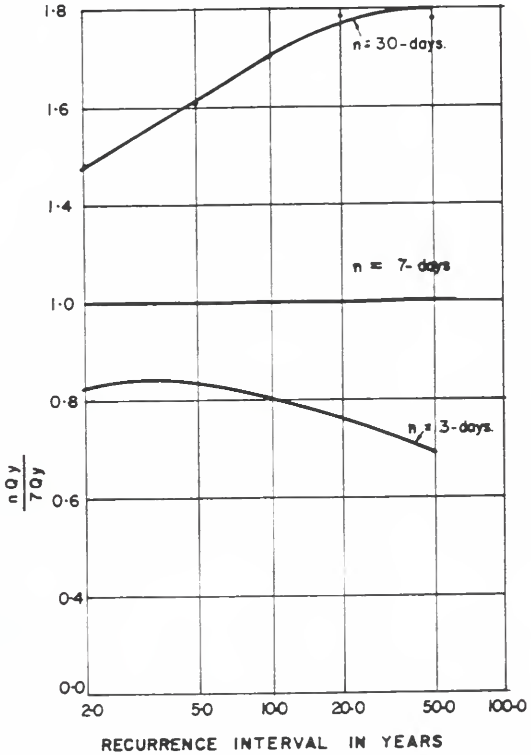
REGIONAL RELATIONSHIP OF 7Q2 AS A FUNCTION OF DRAINAGE AREA.

FIGURE 4.4



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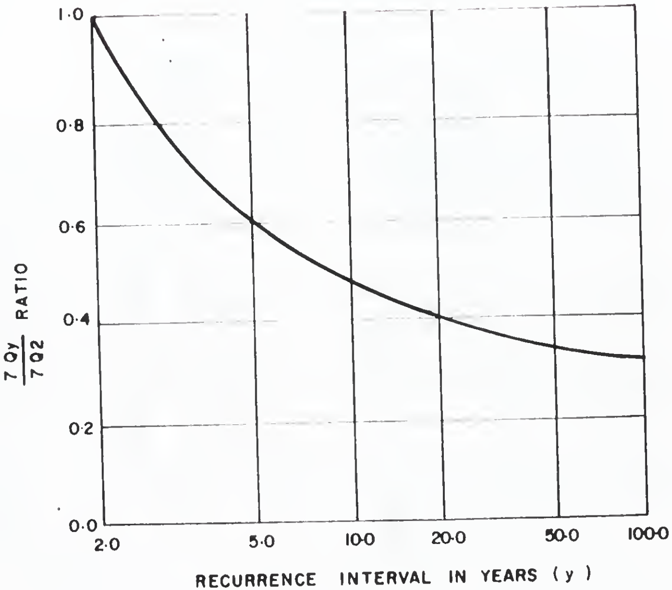
RATIOS OF 3 AND 30 DAY DURATION TO 7 DAY DURATION AS A FUNTION OF RECURRENCE INTERVAL

FIGURE 4.5



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RATIO OF 7Qy/7Q2 FOR RECURRENCE INTERVALS

FIGURE 4·6

accuracy as the regression equations. This is examined in more detail in Section 5.0.

The graphs of n-day low flows to 7-day low flows as well as the graph of 7-day y year recurrence ratio to $7Q_2$ low flows give some insight to the interrelationships between the various extreme value low flows. For example, the ratio of 30 day average low flows to 7 day low flows tends to increase with increased recurrence interval while the ratio of 3 day average low flows to 7 day average low flows decrease with increased recurrence interval. As expected, the 30 day low flows are greater than 7 day low flows (i.e. ratio ranges from 1.5 to 1.8 times the 7 day low flow values). Figure 4.5 illustrates the typical ratios of 7 day y recurrence low flows as a ratio of 7 day 2 year recurrence low flow and how the ratio decreases with increased recurrence interval.

It may be possible to relate shorter periods of record to $7Q_2$ flows and then use the relationships developed here to estimate longer recurrence low flows. This concept is recommended for further research, since it is beyond the scope of this investigation.

4.4 Mapping Proration

In the past it has been common practice to prorate unit flows from nearby gauged watersheds to establish the required low flows. This is done by experienced personnel who have a good understanding of local stream characteristics and other factors within the region (i.e. diversions and regulation, etc.).

For this analysis, the unit area $7Q_{20}$ and Q_{95} flows ($l/s/km^2$) were summarized (as per Section 3.2.7) for stations in the region (see Figure 4.7, in pocket).

The methods of reciprocal distance percentage could be used in the proration estimation (i.e. the distance to nearby gauges would be estimated and unit values could then be weighted by the reciprocal of the distance as a percentage and then averaged).

A statistical summary of average unit low flow characteristics was also undertaken and is summarized in Table 4.6. Area average unit low flow rates ($l/s/km^2$) together with standard deviation for the 5 durations were tabulated for the region for the 2 to 50 year recurrence intervals. It is interesting to note that in most cases, the standard deviations are approximately equal to or greater than the corresponding mean flows.

4.5 Mapping Low Flows

From Section 4.2 it was determined that BFI was the second most important parameter in predicting low flows. Moin and Shaw, 1986 have recently mapped isolines of BFI on a map of Southern Ontario. If it is theoretically possible to map BFI (assumed to be a measure of basin geology and base flow characteristics), then it should be possible to map unit area low flows due to the high correlation previously noted. A regression equaton relating BFI only to unit $7Q_{20}$ flows was determined. The equation was applied to mapped isolines of BFI and the BFI isolines were transferred into unit $7Q_{20}$ isolines (see Figure 4.8). Hence, by identifying the site location on the map estimating the unit $7Q_{20}$ from the isolines and multiplying by the drainage area, $7Q_{20}$ estimates for ungauged sites could be determined.

The R^2 was 0.68 and 0.53 with S.E. of 0.89 and 0.75 for regression equations of $7Q_{20}$ and Q_{95} as a function of BFI. (For this analysis, $7Q_{20}$ and Q_{95} were converted to unit values per kilometer squared and from cubic metres to litres.) The resulting equation illustrated that areas with BFI less than 0.2 would have $7Q_{20}$ values of zero.

TABLE 4.6

Area Averaged Low Flows

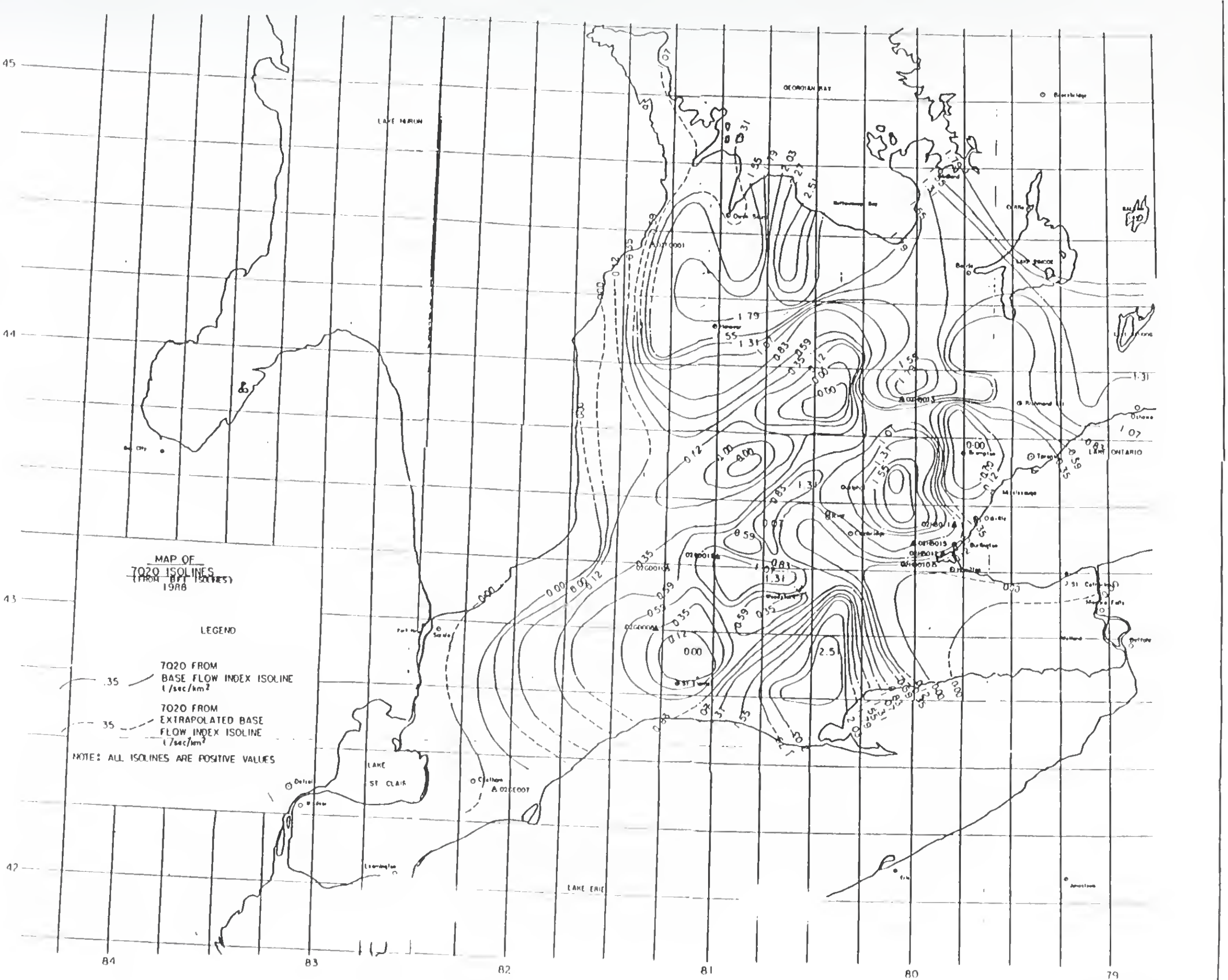
Region	Day Duration	Recurrence Interval (years)										No. of Stations Analysed
		2 Mean (Std.) 1/s/km^2		5 Mean (Std.) 1/s/km^2		10 Mean (Std.) 1/s/km^2		20 Mean (Std.) 1/s/km^2		50 Mean (Std.) 1/s/km^2		
Southwestern & West Central	1	1.14	(1.17)	0.76	(0.96)	0.67	(0.88)	0.52	(0.83)	0.44	(0.78)	100
	3	1.24	(1.24)	0.85	(1.03)	0.70	(0.95)	0.61	(0.89)	0.52	(0.83)	100
	7	1.37	(1.34)	0.97	(1.12)	0.81	(1.03)	0.70	(0.96	0.61	(0.91)	100
	15	1.54	(1.43)	1.11	(1.22)	0.94	(1.13)	0.84	(1.06)	0.74	(1.01)	100
	30	1.81	(1.59)	1.30	(1.36)	1.12	(1.26)	1.00	(1.19)	0.90	(1.13)	100

The method is tested as described in Section 5.0. Further investigation should examine the contouring of unit low flow values directly for comparison of this technique.

4.6 Summary of Estimation Techniques

The regression equations summarized in Table 4.2 appear to best represent low flows (S.E. .19 to .41). Other studies (see Section 2.0) found the S.E. of prediction to range from .30 to .37 for similar sample sizes (Condie, 1985, Chang, 1977, Logan, 1986). Therefore, the prediction errors determined in the present investigation are of smaller magnitude.

The standard error for the BFI isoline conversion equation is higher due to additional error introduced by transforming $7Q_{20}$ and Q_{95} by division of drainage area and conversion from m^3/s to l/s.



MAP OF
7Q20 ISOLINES
(FROM BFI SERIES)
1988

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FIGURE 4.8

5.0 TESTING REGIONALIZATION METHOD

5.1 General

The relative prediction accuracy of the four methods developed in Section 4.0 was examined using 10 stations not included in the development of the regional low flow estimation techniques.

The 10 test stations all have at least 10 years of record, and are active within the last 5 years. Test stations which had independent parameters outside those use in the analysis were not used (i.e. 02HA003, Niagara River at Queenston [DA = 686,000 km^2] and 02GA032 O.A.C. Farm Gauge No. 5 at Guelph [DA = 2.5 km^2]). Unfortunately W.S.C. station 02HB015, Spencer Creek near Westover was subsequently determined to be heavily regulated. Although similar to the analysed data base, the range of drainage areas tend to be on the low side and, therefore, further testing should be completed using more stations with a greater range of independent parameters.

A list of the test stations and their appropriate independent and dependent parameters are given in Table 5.1.

5.2 Testing

Figures 5.1 and 5.2 summarize the results of the analysis techniques compared to estimates from statistically fitted gauged low flows. The Nash-Sutcliffe 1970 model efficiency, R^2, was used to help assess the performance of the identified estimation methods, as calculated below:

$$R^2 = 1 - \frac{\Sigma(Qs - Qo)^2}{\Sigma(Qo - Qm)^2}$$

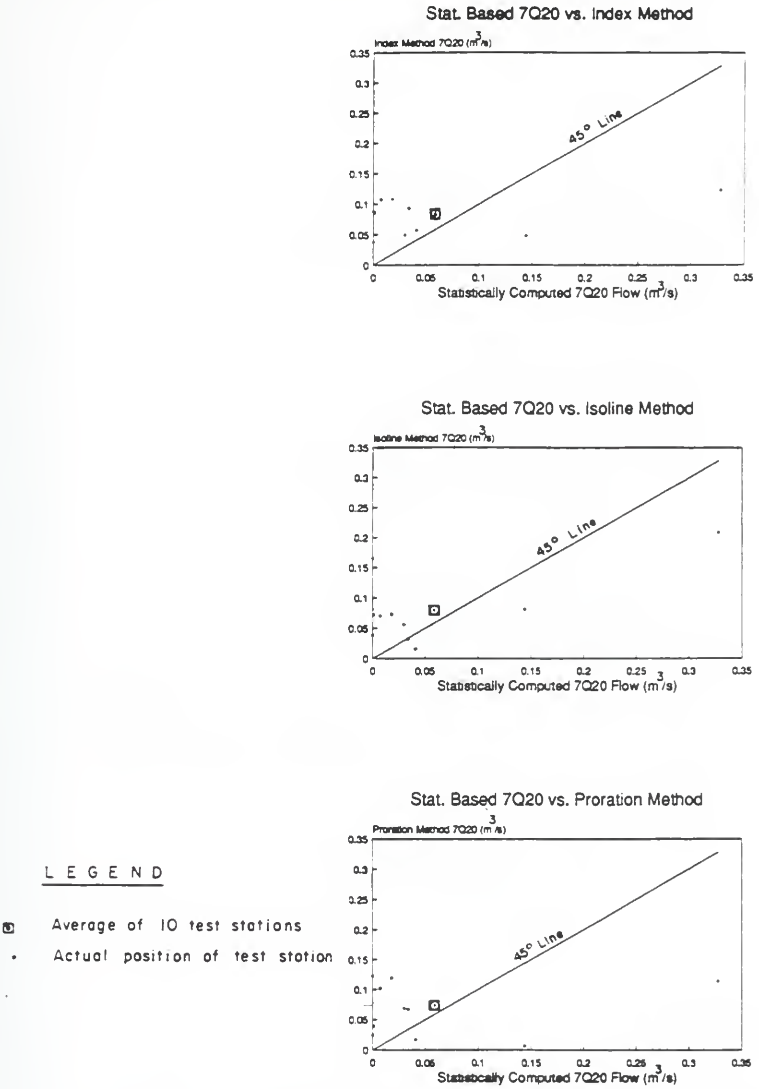
where Qo and Qs are the observed and simulated discharges, and Qm is the mean of the observed discharges.

TABLE 5.1

Summary of Test Station Parameters

Station Number	Station Name	RG	DA (km^2)	BFI Ratio	LEN (km)	MAR (m/m)	MAS (cm)	$7Q_2$ (m^3/s)	$7Q_{20}$ (m^3/s)	$3Q_{20}$ (m^3/s)	$30Q_2$ (m^3/s)	Q_{95} (m^3/s)
02FD001	Pine River at Lurgam	1	154.00	0.24	22.50	442	270	0.003	0.000	0.000	0.013	0.000
02GD008	Medway River at London	2	200.00	0.35	36.40	387	180	0.090	0.007	0.003	0.153	0.085
02GD010	Fish Creek near Prospect Hill	2	150.00	0.35	28.10	384	180	0.030	0.001	0.001	0.053	0.028
02GD019	Trout Creek near Fairview	2	36.00	0.28	10.30	477	220	0.021	0.000	0.000	0.034	0.029
02GE007	McGregor Creek near Chatham	2	202.00	0.15	36.00	300	120	0.048	0.018	0.015	0.098	0.065
02HB010	Spencer Creek at Dundas Cross.	3	166.00	0.52	33.00	345	140	0.103	0.034	0.031	0.172	0.119
02HB011	Bronte Creek near Zimmerman	3	235.00	0.64	30.00	361	140	0.455	0.328	0.309	0.561	0.531
02HB012	Grindstone Creek near Aldershot	3	82.60	0.45	14.00	348	140	0.066	0.041	0.035	0.088	0.076
02HB013	Credit River near Orangeville	3	62.20	0.60	11.00	325	200	0.211	0.144	0.112	0.276	0.227
02HB015 *	Spencer Creek near Westover	3	63.50	0.63	11.50	348	140	0.055	0.030	0.023	0.086	0.079

* station subsequently identified as heavily regulated


Stat. Based 7Q20 vs. Index Method

Stat. Based 7Q20 vs. Isoline Method

Stat. Based 7Q20 vs. Proration Method

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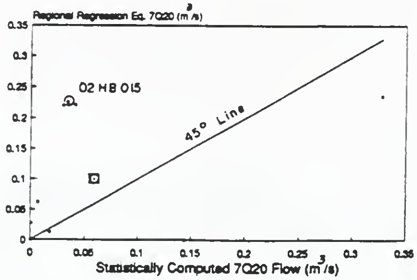
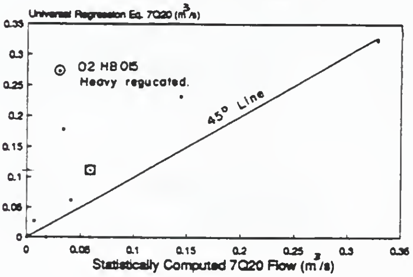
ESTIMATED VERSUS OBSERVED 7Q20 FOR ALTERNATIVE ESTIMATING METHODS

FIGURE 5-1a



Stat. Based 7Q20 vs. Regional Reg. Eq.



Stat. Based 7Q20 vs. Universal Reg. Eq.

LEGEND

⊡ Average of 10 test stations.

• Actual position of test station

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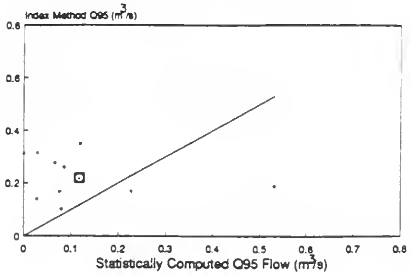
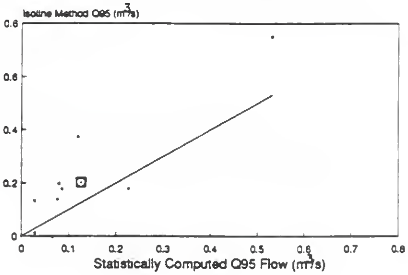
ESTIMATED VERSUS OBSERVED 7Q20 FOR ALTERNATIVE ESTIMATING METHODS

FIGURE 5-1b

Stat. Based Q95 vs. Index Method



Stat. Based Q95 vs. Isoline Method

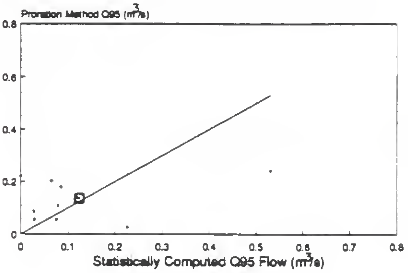


LEGEND

▨ Average of 10 test stations

• Actual position of test station

Stat. Based Q95 vs. Proration Method



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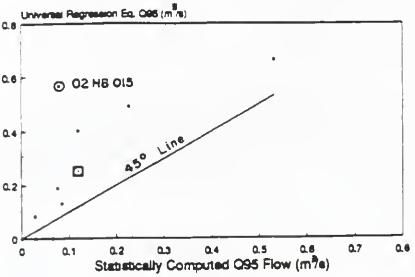
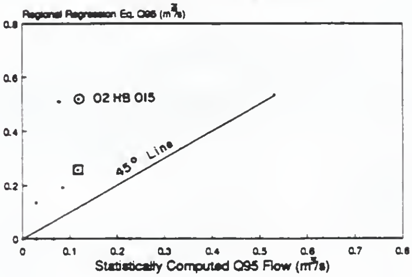
ESTIMATED VERSUS OBSERVED Q 95 FOR ALTERNATIVE ESTIMATING METHODS

FIGURE 5·2 a

Stat. Based Q95 vs. Universal Reg. Eq.



Stat. Based Q95 vs. Regional Reg. Eq.



LEGEND

- ▣ Average of 10 test stations
- • Actual position of test station

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ESTIMATED VERSUS OBSERVED Q 95 FOR ALTERNATIVE ESTIMATING METHODS

FIGURE 5-2b

The results are tabulated in Appendix B. Due to the small sample of test stations the comparison results are used here only to identify the ranking of low flow estimation of methods and not to infer any statistical significance.

The "whole area" regression equation (not sub-regions) provided the best comparison of single station estimate versus "regional method" estimate. However, this method tended to overestimate the majority of the $7Q_{20}$ and Q_{95} low flows. Further analysis (i.e. use of sub-regional equation) did not give comparable results when applied to the test stations.

The remaining three methods ranked 2, 3, 4 as Isoline Method, Index Method, Proration Method respectively.

The isoline method resulted in fairly good results but should be tested with a larger range and number of stations. This method tended to overestimate smaller low flows and underestimate larger low flows in this sample test data set. The heavily regulated station was estimated by the isoline method better than the regression equations which were formed without heavily regulated stations. Further investigation into mapping isolines of low flow should, therefore, be undertaken. This method had the highest Nash-Sutcliffe R^2 value for estimating Q_{95} for the 10 test stations.

The index method showed similar results to that of the isolines method in that it overestimated smaller values and underestimated larger values.

The proration method (using nearby gauges) did not perform as well as the three alternate estimation methodologies developed from this study.

Therefore, as an overall conclusion, the Regression technique (having a Nash Sutcliffe R^2 of .69) relating drainage area, base flow index and length to low flows has been determined as the best method for estimating $7Q_{20}$ low flows for non-regulated ungauged watersheds with drainage areas 14 km^2 to 4000 km^2, BFI indices .10 to .80 and Lengths from 6 km to 190 km.

5.3 Sensitivity Analysis

The Regression equations identified above for $7Q_{20}$ and Q_{95} values were examined with respect to sensitivity of parameter estimation. Table 5.2 summarizes the percentage difference from the mean parameter estimation by varying each parameter by ±15%. It is noted that $7Q_{20}$ and Q_{95} values are sensitive to BFI and Length parameters (15% change causes 27 to 38% and 15 to 25% change for BFI and LEN respectively in the estimated value). Both BFI and LEN overestimates cause higher errors than the corresponding underestimates. Therefore, care should be taken in estimating these parameters for ungauged watersheds.

TABLE 5.2

Summary of Sensitivity Analysis

$$7Q_{20} = -.166 + 9.03\times10^{-11}\ DA^3 + 1.10\ BFI^2 + 8.35\times10^{-5}\ LEN^2$$

$$Q_{95} = -.23 + 1.26\times10^{-10}\ DA^3 + 1.98\ BFI^2 + 8.97\times10^{-5}\ LEN^2$$

Values of $7Q_{20}$ (m^3/s) Varying with ±15% in Indicated Parameters

DA		BFI		LEN	
$7Q_{20}$ (m^3/s)	(% Diff)	$7Q_{20}$ (m^3/s)	(% Diff)	$7Q_{20}$ (m^3/s)	(% Diff)
.227	7	.167	27	.180	21
.230	0	.230	0	.230	0
.233	7	.303	30	.288	25

Values of Q_{95} (m^3/s) with Varying Parameters

DA		BFI		LEN	
Q_{95} (m^3/s)	(% Diff)	Q_{95} (m^3/s)	(% Diff)	Q_{95} (m^3/s)	(% Diff)
.348	1	.240	31	.299	15
.352	0	.352	0	.352	0
.356	1	.484	38	.414	18

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

1. Regressions utilizing Drainage Area, Base Flow Index and Stream Length as independent parameters provide reasonable estimates of low flow values (see Table 4.4).

2. The equations for estimating low flows are sensitive to variations in values of Base Flow Index (BFI) and Length (LEN). Care should be taken in estimating these parameters for ungauged watersheds. From the literature review, it is apparent that even short term gauging (i.e. 2 years) can provide good estimates of BFI. Alternatively, available maps of BFI isolines can be used.

3. The index, or graphical method, was also found to give reasonable estimates of low flow characteristics. Both the regression and graphical methods appear to provide low flow estimates superior to those obtained solely from area proration to gauged sites.

4. Statistical tests on the data base indicated that the series of extreme low flows may exhibit some trend and persistence with some possibility of non-random characteristics.

6.2 Recommendations

1. The reasons for trend, persistence and non-randomness characteristics should be further examined. This should include an analysis of the applicability of the statistical tests in addition to an evaluation of other factors such as climatic trends and variations in groundwater storage and aquifer conditions.

2. To maintain a relevant data base of recent low flow characteristics for the regions, the analysis of single station low flow characteristics should be updated and results remapped every 5 years.

3. The regionalization methods which were developed should be tested on a larger data base to support the findings of this study and provide refinements to estimating procedures for other regions. This should include further investigation on the form of the regression equation and identification of sub-regions, etc. The practical advantages of utilizing untransformed independent parameters (DA, BFI, LEN) should be further assessed in order of scatter at test locations and the small size of the regression coefficients, etc.

4. The index method should be extended using all available short term station data to refine the estimates of $7Q_2$ values as a function of drainage area. This would maximize use of the available data base.

5. Isoline maps of unit low flow values should be prepared using station estimates and compared to the results of mapping using the BFI regression/conversion method.

6. These techniques for estimating low flow values at ungauged sites should be extended to the remaining four Ministry of Environment Regions:

    i) Central Ontario Region
    ii) Southeastern Region
    iii) Northwestern Region
    iv) Northeastern Region

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APPENDIX A

STATISTICAL ANALYSIS PROCEDURES

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APPENDIX A

STATISTICAL ANALYSIS PROCEDURES

APPENDIX A

STATISTICAL ANAYSIS PROCEDURES

TABLE OF CONTENTS

A.1 Extreme Value Analysis

A.2 Flow Duration Analysis

A.3 Non-parametric Tests for Independence, Trend and Randomness

- A.3.1 Test Description
  - A.3.1.1 Introduction
  - A.3.1.2 The Spearman Rank Order Serial Correlation Coefficient for Independence
  - A.3.1.3 The Spearman Rank Order Correlation Coefficient Test for Trend
  - A.3.1.4 Runs Above and Below the Median for General Randomness
- A.3.2 Summary of Test Results

APPENDIX A.1

EXTREME VALUE ANALYSIS

MARCH, 1990

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APPENDIX A.1
EXTREME VALUE ANALYSIS

Introduction

Statistical distributions allow estimates of probability of exceedance of events to be made by analytical techniques. Various methods are available, and a good discussion is given by McMahon and Mein (ref 9).

At a gauged location, average low flows can be determined for selected durations of time for each year of record. For example, the corresponding minimum average consecutive 15-day low flow can be determined for each annual record. The series of 15-day average annual low flows can then be ranked lowest to highest and an extreme value analysis undertaken using a theoretical distribution.

The Gumbel Extreme Value Distribution is commonly used for fitting low flow frequency curves to the available data.

The Gumbel Type III Distribution

This is a variation of Fisher and Tippett's third asymnptotic distribution of extreme values and is sometimes referred to as the Weibull distribution. In view of his many contributions it is often referrred to in hydrology as the Gumbell II. The probability density function is:

$$\phi(x) = \frac{a}{u - e} \left\{ \frac{x - e}{u - e} \right\}^{a-1} \exp \left[- \left\{ \frac{x - e}{u - e} \right\}^{a} \right] \qquad (1)$$

where e is the lower bound parameter
u is the characteristic drought
and a is the shape parameter

Various methods are available for determining the distribution parameters for a particular data set. See references 2 and 6 for example.

The Probability Function

The density function is integrable and gives the distribution function

$$F\ (x) = 1 - \exp \left[- \left\{ \frac{x - e}{u - e} \right\}^{a} \right] \qquad (2)$$

which gives the probability of non-exceedance of x.
Since it is more common to require x for a given probability of non-exceedance, a simple re-arrangement gives

$$x = e + (u - e) \left\{ - \ln \left[1 - F(x) \right]^{1/a} \right\} \qquad (3)$$

There are occasions when the sample series of low flows can have a large negative coefficient of skewness, and since the Gumbel Type III distribution cannot have a skewness of less than -1.14, then the distribution cannot be fitted.

There are insuffucient natural samples available with such low skewness to make a firm choice of an alternative treatment, but from the few available, it was found that the negatively skewed three-parameter lognormal distribution provided an acceptable alternative.

If $y = \ln (a-x)$ is normally distributed, then the probability density function of x is given by

$$\phi(x) = \frac{1}{(a-x)\sigma\sqrt{2\Pi}} \exp \left\{ - \frac{1}{2\sigma^2} \left[\ln\ (a-x) - m \right]^2 \right\} \qquad (4)$$

where m and σ are respectively the mean and standard deviation of the series $\ln (a-x)$ and a is an lower boundary parameter. This form of the distribution can only have negative skewness. The equation in the form $\ln (x-a)$ is for distributions with positive skewness.

Taking moments, re-arranging and replacing them by their sample estimates gives:

$$k^3 + 3k - g_1 = 0 \qquad (36a) \quad (5)$$

and after solving for k

$$\hat{a} = x - s/k \qquad (37a) \quad (6)$$

$$\hat{m} = \ln(-s/k) - 1/2\ln(k^2+1) \qquad (38a) \quad (7)$$

$$\sigma^2 = \ln(k2+1) \qquad (39a) \quad (8)$$

Thus, the distribution is completely defined and the T-year low flows can be computed from:

$$Q_T = \hat{a} - \exp(\hat{m}\ \sigma t) \qquad (9)$$

Additional details are discussed in the user's manual.

Source: Condie, R., L. C. Cheng
"Low Flow Frequency Analysis - Program LOFLOW",
Water Resources Branch, Inland Waters Directorate
Environment Canada, Ottawa, 1987

APPENDIX A.2
FLOW DURATION ANALYSIS

MARCH, 1990

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APPENDIX A.2

FLOW DURATION ANALYSIS

A flow duration curve is a plot of the flow of a stream against the percent of time the indicated flow was equalled or exceeded during the period covered by the available flow data. This curve is extremely useful for hydro power studies and for characterizing the local streamflow regime.

An empirical procedure was used to analyse each sample discharge record. Flow duration curves are derived by rearranging the available daily or monthly flow data in order of magnitude. The total time period represents 100% of the time. Therefore, by definition of the procedure used here, the largest value is exceeded 0 percent of the time and the smallest value is exceeded 100% of the time.

The flow duration curve represents the percent of time that a specific discharge occurs at that location. However, the curve does not indicate the period of time in the year when the flow is less than or equal to the selected value. Therefore, in some instances, it is also useful to develop flow duration curves on a monthly basis, that is, all data for the month of January over the entire period of record is analysed independently to produce a flow duration curve representative of flow conditions in January.

Single station flow duration analyses and corresponding monthly flow duration curves have been determined at all relevant stream and flow locations across the Province.

APPENDIX A.3

NON-PARAMETRIC TESTS

INDEPENDENCE TREND AND RANDOMNESS

MARCH, 1990

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APPENDIX A.3

NONPARAMETRIC TESTS FOR INDEPENDENCE, TREND AND RANDOMNESS

A.3.1 Test Description

This appendix briefly summarizes the functions evaluated in the LFA package and gives the methods used to determine their statistical significance.

A.3.1.1 Introduction

Any statistical test of significance will generally be made using the following steps:

a) State the null hyposthesis, H_0. For instance in split sample tests, the null hypothesis may be that there is no difference between the sample means.

b) Choose a significance level, a.

c) Choose an appropriate statistical test. In this program all tests are nonparametric.

d) Compute the test statistic.

e) The sampling distribution of the test statistic is known and has been tabulated, and the chosen significance level then defines the region of rejection.

f) If the computed test statistic lies in the region of rejection, then the null hypothesis is rejected.

Consider now the four tests in this program.

A.3.1.2 The Spearman Rank Order Serial Correlation Coefficient for Independence

If the series Q_i with i ranging from 1 to N is put in chronological order, two time series are formed and their respective ranks computed:

Q_1, Q_2 ....Q_{N-1} by x_i, the rank of Q_i; i=1; N-1
and Q_2, Q_3 ....Q_N by y_i, the rank of Q_i; i=2, N

then Spearman rank order serial correlation coefficient is

$$S_1 = \tfrac{1}{2}\,(\Sigma x_i^2 + \Sigma y_i^2 - \Sigma d_i^2)\,(\Sigma x_i^2\ \Sigma y_i^2)^{-\frac{1}{2}} \qquad (1)$$

where $\Sigma x_i^2 = (m^3-m)/12 - \Sigma T x$

$\Sigma y_i^2 = (m^3-m)/12 - \Sigma T_y$

d_i is the difference in rank between x_i and y_i

$m = N-1$

and the summations are over the m pairs of x_i, y_i.

Ignoring for the moment the terms in T and putting them at zero, equation (a) becomes

$$S_1 = 1-(6\Sigma d_i^2)\ (m^3-m) \qquad (2)$$

the more familiar form of the Spearman rank correlation coefficient.

The terms in T adjust for tied ranks and are computed as follows. If for instance three observations in the x series were tied for ranks 17, 18, and 19 then each observation is given the rank 18; if two were tied for ranks 24 and 25, then each is ranked 24.5.

For each tied set, T is computed from

$$T_x = (J^3 - J)/12$$

where J is the number of observations tied at a give rank. ΣT_x and ΣT_y are defined by the extension of the foregoing. When N is 10 or greater, then the function

$$t = S_1 \, [(m-2)/(1-S_1^2)]^{1/2} \tag{3}$$

is distributed like Student's t with m-2 degrees of freedom. A one-tail test must be used.

A.3.1.3 The Spearman Rank Order Correlation Coefficient Test for Trend

If the series Q_i with i ranging from 1 to N is put in chronological order, ranks assigned and denoting the series

Q_1, Q_2 ....Q_N by y_i, the rank of Q_i
and 1, 2, ...N by x_i, the sequential order of Q_i

then the Spearman rank order correlation coefficient r_s is calculated as in equation 1, except that $m = N$, $T_x = 0$, and the summations are taken over the N pairs of x_i, y_i.

For N = 10 or greater, then the function

$$t = r_s \, [(N-2)/(1-r_s^2)]^{1/2} \tag{4}$$

is distributed like Student's t with N-2 degrees of freedom. The null hypothesis is that there is no trend, either upward or downward with time, and so a two-tail test is used.

A.3.1.4 Runs Above and Below the Median for General Randomness

This randomness test is based on the order or sequence in which the individual scores or observations were obtained. Actually, the test is based on the number of runs which a sample exhibits.

A run is defined as a succession of identical symbols which are followed and preceded by different symbols or by no symbols at all.

The total number of runs in a sample of any given size gives an indication of whether or not the sample is random. If very few runs occur, a time trend or some bunching due to lack of independence is suggested. If a great many runs occur, systematic short-period cyclical fluctuations seem to be influencing the sample.

For example, once the median of the sample has been determined, each observation can be labelled as being above and equal to or below and equal to the median. If "A" represents above and equal to the median and "B" represents below and equal to the median, then a sample may be ordered as

AABBBABBBBAABA

(A run represents a succession of identical symbols). For our example, each run is underscored and numbered consecutively:

$$\underset{1}{\underline{AA}} \quad \underset{2}{\underline{BBB}} \quad \underset{3}{\underline{A}} \quad \underset{4}{\underline{BBBB}} \quad \underset{5}{\underline{AA}} \quad \underset{6}{\underline{B}} \quad \underset{7}{\underline{A}}$$

This sample begins with 2 observations above or equal to the median, followed by a run of 3 observations below or equal to the median, etc.

Seven runs are observed in all: that is, the total number of runs above and below the median RUNAB, is 7. If n_1 represents the number of events of type A, then $n_1 = 6$. If n_2 denotes the number below the median, type B, then $n_2 = 8$. Thus, the number of observations is equal to $(n_1 + n_2)$.

In order to apply this run test, one must determine n_1, n_2 and RUNAB.

The null hypothesis, H_0, is that the A's and B's occur in random order. The alternate hypothesis, H_1, is that the order of the A's and B's deviates from randomness.

When either n_1 or n_2 is greater than 20, the sampling distribution of RUNAB tends to normality with

$$z = \frac{|\text{RUNAB} - [(2n_1n_2)/(n_1+n_2)+1]\ |}{\{2n_1n_2(2n_1n_2-n_1-n_2)/[(n_1+n_2)^2(n_1+n_2-1)]^{\frac{1}{2}}} \qquad (5)$$

where z is an N(0,1) variate as described in Table A.4. This package uses a region of rejection defined by

z greater than 1.96 for $\alpha = .05$
z greater than 2.575 for $\alpha = .01$

A.3.2 Summary of Tests Results

All stations for each region are tabulated as to whether the station data shows independence, free from trend and random for significant levels of 1% and 5% in Table 3.2, Section 3.0). It can be seen from the summary table that a large number of the data sets for the stations fail the non-parametric test to the point that the binomial probability of this number of failures is "0". Therefore, the data is dependent, is not free from trend and is not random. Hence, some degree of scepticism should be used when using the extreme value predicted flows from this study.

To examine effects of length of record and regulation, the analysis was completed using criteria of $\geq$20 years of record, <20 years of record and regulated vs. non-regulated station data. These subgroups are also indicated on Table 3.2.

The regulated stations show a greater percentage of values which can be said to pass the non-parametric test compared to those which failed, although the binomial probability is still "0".

The data sets for stations with less than 20 years of record suggest that neither the length of record or the regulation can account for the dependence, trend and non-randomness of the data sets.

It is also noted that the data tended to be more significant with respect to the increasing length of duration for which the sample represents. Further investigation is beyond the scope of this study.

APPENDIX B
TEST STATION ANALYSIS

APPENDIX B

Table B.1 summarizes the Nash-Sutcliffe model efficiency R^2.

$$R^2 = 1 - \frac{\sum(Q_s - Q_o)^2}{\sum(Q_o - Q_m)^2}$$

where Q_o = observed flow

Q_s = simulated flow

Q_m = mean of observed flow

The efficiency equation compares the simulated and observed flow differences compared to the observed differences.

The first part of Table B.1 illustrates the observed flows and the denominator of the efficiency equation. The following sections summarize the resulting estimates via the four estimation techniques and the numerator of the efficiency equation. Note the Nash-Sutcliffe efficiency equation R^2 is not equivalent to regression equations coefficient of determination.

TABLE B.1
COMPARISON OF ESTIMATED VS ACTUAL LOW FLOWS (9 STATIONS)

STATISTICALLY COMPUTED GAUGED INFORMATION

	7Q2	7Q20	(QO-QM)^2	Q95	(QO-QM)^2
02FD001	0.003	0.000	0.004	0.000	0.017
02GD008	0.090	0.007	0.003	0.085	0.002
02GD010	0.030	0.001	0.004	0.028	0.010
02GD019	0.021	0.000	0.004	0.029	0.010
02GE007	0.048	0.018	0.002	0.065	0.004
02HB010	0.103	0.034	0.001	0.119	0.000
02HB011	0.455	0.328	0.070	0.531	0.162
02HB012	0.066	0.041	0.001	0.076	0.003
02HB013	0.211	0.144	0.006	0.227	0.010
AVG	0.11	0.06	0.01	0.13	0.02
STD	0.13	0.10	0.02	0.16	0.05
SUM	1.03	0.57	0.10	1.16	0.22

ALL STATIONS REGRESSION

	7Q2	7Q20	(QS-QO)^2	Q95	(QS-QO)^2
02FD001	0.000	0.000	0.000	0.000	0.000
02GD008	0.126	0.027	0.000	0.132	0.002
02GD010	0.081	0.002	0.000	0.084	0.003
02GD019	0.000	0.000	0.000	0.000	0.001
02GE007	0.000	0.000	0.000	0.000	0.004
02HB010	0.353	0.179	0.021	0.404	0.081
02HB011	0.571	0.324	0.000	0.663	0.018
02HB012	0.165	0.062	0.000	0.189	0.013
02HB013	0.421	0.232	0.008	0.494	0.071
AVG	0.19	0.09	0.00	0.22	0.02
STD	0.20	0.12	0.01	0.23	0.03
SUM	1.72	0.83	0.03	1.97	0.19
R2			0.69		0.11

REGIONAL REGRESSION EQUATIONS

	7Q2	7Q20	(QS-QO)^2	Q95	(QS-QO)^2
02FD001	0.000	0.000	0.000	0.000	0.000
02GD008	0.160	0.062	0.003	0.192	0.011
02GD010	0.113	0.028	0.001	0.136	0.012
02GD019	0.000	0.000	0.000	0.000	0.001
02GE007	0.000	0.013	0.000	0.000	0.004
02HB010	0.279	0.226	0.037	0.517	0.159
02HB011	0.496	0.236	0.009	0.535	0.000
02HB012	0.173	0.221	0.032	0.509	0.187
02HB013	0.399	0.000	0.021	0.000	0.052
AVG	0.18	0.09	0.01	0.21	0.05
STD	0.17	0.10	0.01	0.23	0.07
SUM	1.62	0.78	0.10	1.89	0.43
R2			-0.07		-0.96

TABLE B.1
COMPARISON OF ESTIMATED VS ACTUAL LOW FLOWS (9 STATIONS)

INDEX METHOD

	7Q2	7Q20	(QS-QO)^2	Q95	(QS-QO)^2
02FD001	0.219	0.088	0.008	0.312	0.098
02GD008	0.268	0.107	0.010	0.260	0.031
02GD010	0.215	0.086	0.007	0.140	0.013
02GD019	0.094	0.038	0.001	0.314	0.081
02GE007	0.270	0.108	0.008	0.277	0.045
02HB010	0.232	0.093	0.003	0.349	0.053
02HB011	0.305	0.122	0.042	0.189	0.117
02HB012	0.144	0.057	0.000	0.167	0.008
02HB013	0.122	0.049	0.009	0.169	0.003
AVG	0.21	0.08	0.01	0.24	0.05
STD	0.07	0.03	0.01	0.07	0.04
SUM	1.87	0.75	0.09	2.18	0.45
R2			0.06		-1.07

PRORATED UNIT GAUGED VALUES

	7Q2	7Q20	(QS-QO)^2	Q95	(QS-QO)^2
02FD001	0.236	0.122	0.015	0.221	0.049
02GD008	0.236	0.102	0.009	0.179	0.009
02GD010	0.122	0.039	0.001	0.088	0.004
02GD019	0.058	0.025	0.001	0.056	0.001
02GE007	0.242	0.119	0.010	0.203	0.019
02HB010	0.131	0.067	0.001	0.140	0.000
02HB011	0.196	0.114	0.046	0.242	0.084
02HB012	0.055	0.017	0.001	0.056	0.000
02HB013	0.032	0.007	0.019	0.027	0.040
AVG	0.15	0.07	0.01	0.13	0.02
STD	0.08	0.04	0.01	0.08	0.03
SUM	1.31	0.61	0.10	1.21	0.21
R2			-0.08		0.05

ISOLINE MAPS FROM BFI INDEX MAP

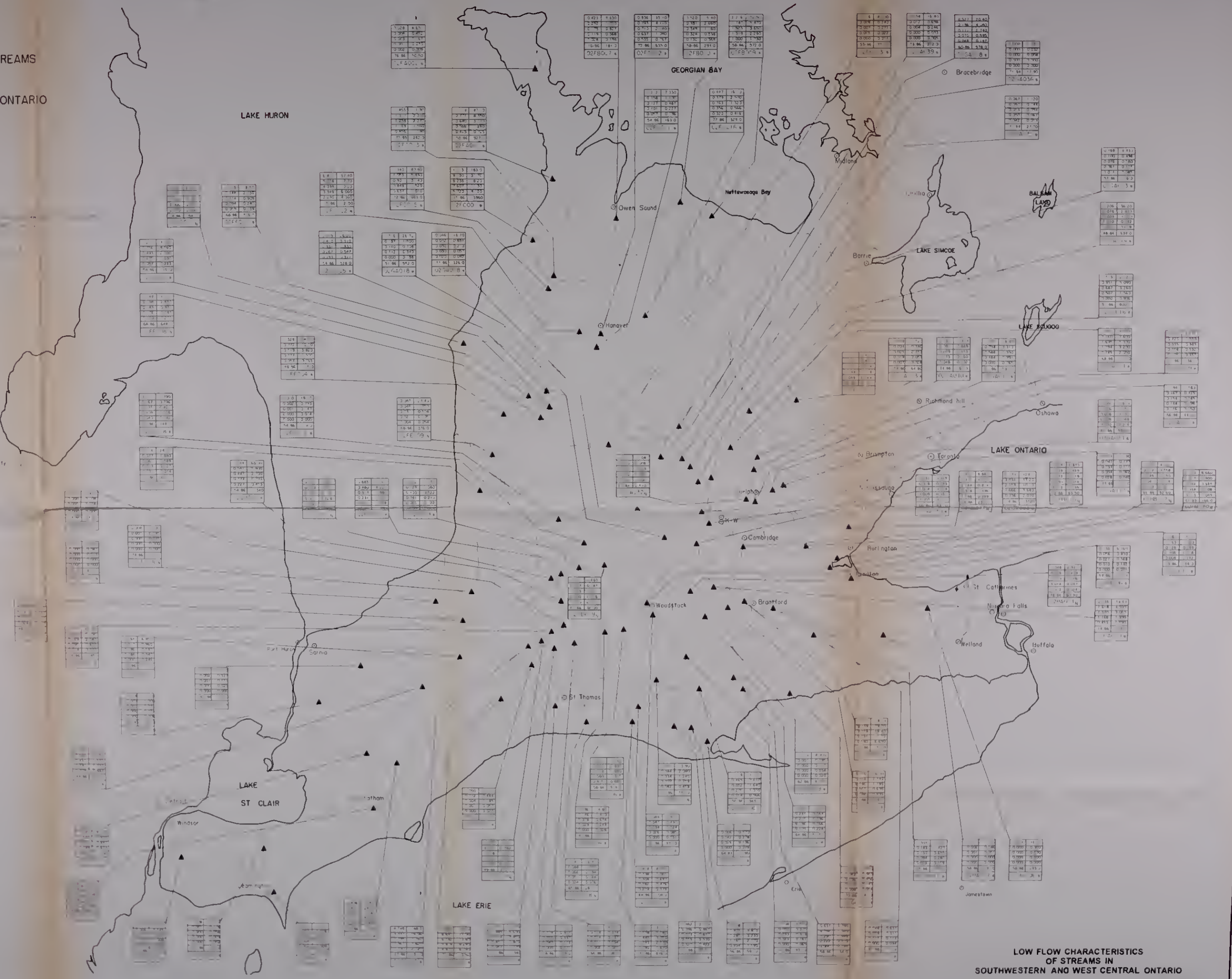
	7Q20	(QS-QO)^2	Q95	(QS-QO)^2
02FD001	0.165	0.027	0.002	0.000
02GD008	0.070	0.004	0.177	0.008
02GD010	0.072	0.005	0.133	0.011
02GD019	0.039	0.002	0.012	0.000
02GE007	0.073	0.003	0.000	0.004
02HB010	0.033	0.000	0.372	0.064
02HB011	0.209	0.014	0.751	0.048
02HB012	0.016	0.001	0.139	0.004
02HB013	0.081	0.004	0.179	0.002
AVG	0.08	0.01	0.20	0.02
STD	0.06	0.01	0.23	0.02
SUM	0.76	0.06	1.76	0.14
R2		0.37		0.34

UNIT LOW FLOW CHARACTERISTICS OF STREAMS IN SOUTHWESTERN AND WEST CENTRAL ONTARIO

Cumming Cockburn Limited
Consulting Engineers and Planners

LOW-FLOW CHARACTERISTICS OF STREAMS
IN
SOUTHWESTERN AND WEST CENTRAL ONTARIO

MINISTRY OF THE ENVIRONMENT
WATER RESOURCES BRANCH



LOW FLOW CHARACTERISTICS
OF STREAMS IN
SOUTHWESTERN AND WEST CENTRAL ONTARIO

Cumming Cockburn Limited
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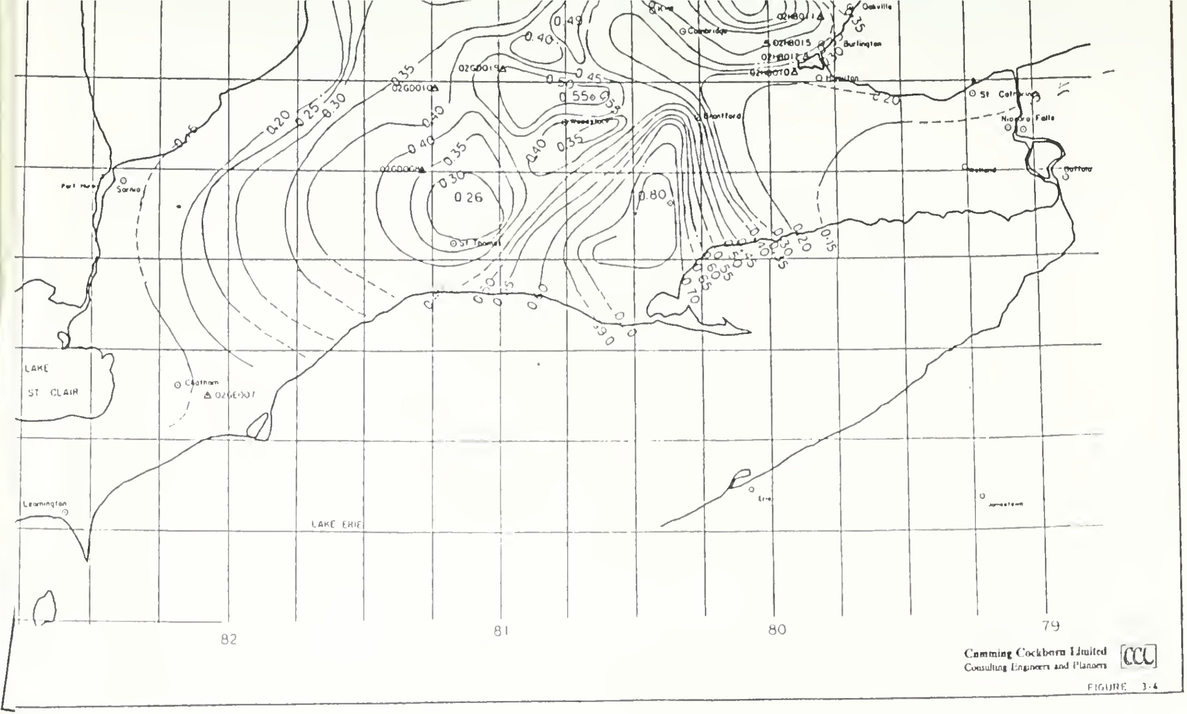

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CCL

FIGURE 3-4

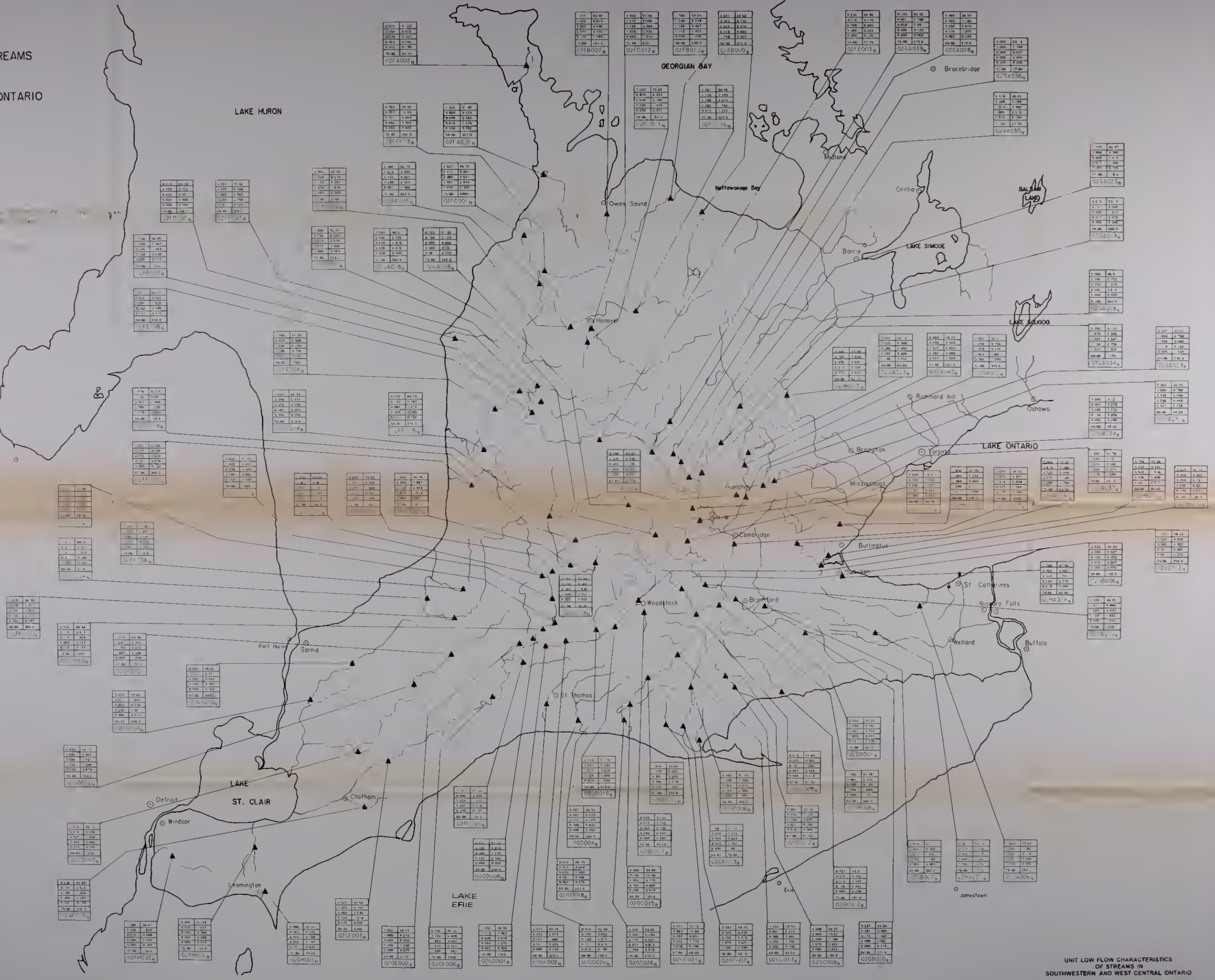
02GA016 GRA
02GA0 8 NITH RIVER AT

UNIT
LOW-FLOW CHARACTERISTICS OF STREAMS
IN
SOUTHWESTERN AND WEST CENTRAL ONTARIO

MINISTRY OF THE ENVIRONMENT
WATER RESOURCES BRANCH

7Q2	[illegible]
7Q5	[illegible]
7Q10	[illegible]
7Q20	[illegible]
MIN DAY	99%DUR
PERIOD	AREA
STATION # AC	

[illegible]	SAUBLE RIVER AT SAUBLE FALLS
[illegible]	STOKES RIVER NEAR FERNDALE
[illegible]	SYDENHAM RIVER NEAR OWEN SOUND
02FB009	BEAVER RIVER NEAR CLARKSBURG
02FB0	BIGHEAD RIVER NEAR MEAFORD
02FC0	SAUGEEN RIVER NEAR PORT ELGIN
[illegible]	SAUGEEN RIVER NEAR WALKERTON
[illegible]	[illegible] CREEK NEAR [illegible]
[illegible]	SOUTH SAUGEEN RIVER NEAR HANOVER
[illegible]	NORTH SAUGEEN RIVER NEAR [illegible]
[illegible]	TEESWATER RIVER NEAR PAISLEY
[illegible]	[illegible] RIVER ABOVE DURHAM
[illegible]	PINE RIVER AT [illegible]
[illegible]	MAITLAND RIVER BELOW WINGHAM
[illegible]	MIDDLE MAITLAND RIVER NEAR [illegible]
[illegible]	MAITLAND RIVER NEAR [illegible]
[illegible]	MAITLAND RIVER ABOVE WINGHAM
[illegible]	LITTLE MAITLAND RIVER AT [illegible]
[illegible]	MIDDLE MAITLAND RIVER NEAR [illegible]
[illegible]	SOUTH MAITLAND RIVER AT SUMMERHILL
[illegible]	AUSABLE RIVER NEAR SPRINGBANK
[illegible]	BAYFIELD RIVER NEAR VARNA
[illegible]	PARKHILL CREEK ABOVE PARKHILL [illegible]
[illegible]	GRAND RIVER AT GALT
[illegible]	NITH RIVER NEAR CANNING
[illegible]	GRAND RIVER NEAR MARSVILLE
[illegible]	SPEED RIVER BELOW GUELPH
[illegible]	GRAND RIVER BELOW SHAND DAM
[illegible]	[illegible]
[illegible]	[illegible] CREEK NEAR [illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	ERAMOSA RIVER ABOVE [illegible]
[illegible]	ALDER CREEK NEAR [illegible]
[illegible]	BLUE SPRINGS CREEK [illegible]
[illegible]	[illegible]
[illegible]	[illegible] CREEK NEAR
[illegible]	GRAND RIVER AT [illegible]
[illegible]	EAST [illegible] CREEK NEAR [illegible]
02GA038	CANAGAGIGUE CREEK NEAR [illegible]
[illegible]	SCHNEIDER CREEK AT KITCHENER
[illegible]	NITH RIVER ABOVE NITHBURG
[illegible]	CONESTOGO RIVER ABOVE [illegible]
02GA040	SPEED RIVER NEAR ARMSTRONG MILLS
[illegible]	GRAND RIVER AT BRANTFORD
[illegible]	HORNER CREEK NEAR PRINCETON
[illegible]	FAIRCHILD CREEK NEAR BRANTFORD
[illegible]	WHITEMANS CREEK NEAR [illegible]
[illegible]	KENNY CREEK NEAR BURFORD
[illegible]	MCKENZIE CREEK NEAR [illegible]
[illegible]	KETTLE CREEK AT ST. THOMAS
[illegible]	BIG CREEK NEAR [illegible]
[illegible]	BIG CREEK NEAR WALSINGHAM
[illegible]	LYNN RIVER AT SIMCOE
[illegible]	BIG OTTER CREEK AT TILLSONBURG
[illegible]	PATTERSON CREEK NEAR [illegible]
[illegible]	DEDRICK CREEK NEAR PORT ROWAN
[illegible]	LITTLE OTTER CREEK NEAR [illegible]
[illegible]	BIG OTTER CREEK ABOVE OTTERVILLE
[illegible]	CATFISH CREEK NEAR SPARTA
[illegible]	VENISON CREEK NEAR WALSINGHAM
[illegible]	NANTICOKE CREEK AT NANTICOKE
[illegible]	BIG OTTER CREEK NEAR [illegible]
[illegible]	THAMES RIVER NEAR EALING
[illegible]	NORTH THAMES RIVER BELOW FANSHAWE DAM
[illegible]	MIDDLE THAMES RIVER AT THAMESFORD
[illegible]	NORTH THAMES RIVER AT ST. MARYS
[illegible]	MEDWAY RIVER AT LONDON
[illegible]	TROUT CREEK NEAR ST. MARYS
[illegible]	FISH CREEK NEAR PROSPECT HILL
[illegible]	CEDAR CREEK AT WOODSTOCK
[illegible]	THAMES RIVER AT WOODSTOCK
[illegible]	[illegible] CREEK NEAR THORNDALE
[illegible]	NORTH THAMES RIVER NEAR MITCHELL
[illegible]	NORTH THAMES RIVER NEAR THORNDALE
[illegible]	THAMES RIVER AT INNERKIP
[illegible]	[illegible] RIVER BELOW [illegible]
[illegible]	[illegible] CREEK NEAR [illegible]
[illegible]	[illegible] CREEK NEAR DORCHESTER
[illegible]	THAMES RIVER AT BYRON
[illegible]	THAMES RIVER AT THAMESVILLE
[illegible]	[illegible] CREEK BELOW [illegible]
[illegible]	THAMES RIVER NEAR [illegible]
[illegible]	MCGREGOR CREEK NEAR CHATHAM
[illegible]	SYDENHAM RIVER NEAR ALVINSTON
[illegible]	BEAR CREEK ABOVE WILKESPORT
[illegible]	SYDENHAM RIVER AT STRATHROY
[illegible]	BEAR CREEK NEAR PETROLIA
[illegible]	SYDENHAM RIVER NEAR DRESDEN
02GH001	STURGEON CREEK NEAR LEAMINGTON
02GH002	RUSCOM RIVER NEAR RUSCOM STATION
02GH003	CANARD RIVER NEAR LUKERVILLE
02HA006	TWENTY MILE CREEK AT BALLS FALLS
02HA007	WELLAND RIVER BELOW CAISTOR CORNERS
02HA014	REDHILL CREEK AT HAMILTON
02HB0 0	SPENCER CREEK AT DUNDAS CROSSING
02HB011	BRONTE CREEK NEAR ZIMMERMAN
02HB012	GRINDSTONE CREEK NEAR ALDERSHOT
02HB013	CREDIT RIVER NEAR ORANGEVILLE
02HB015	SPENCER CREEK NEAR WESTOVER



UNIT LOW FLOW CHARACTERISTICS
OF STREAMS IN
SOUTHWESTERN AND WEST CENTRAL ONTARIO

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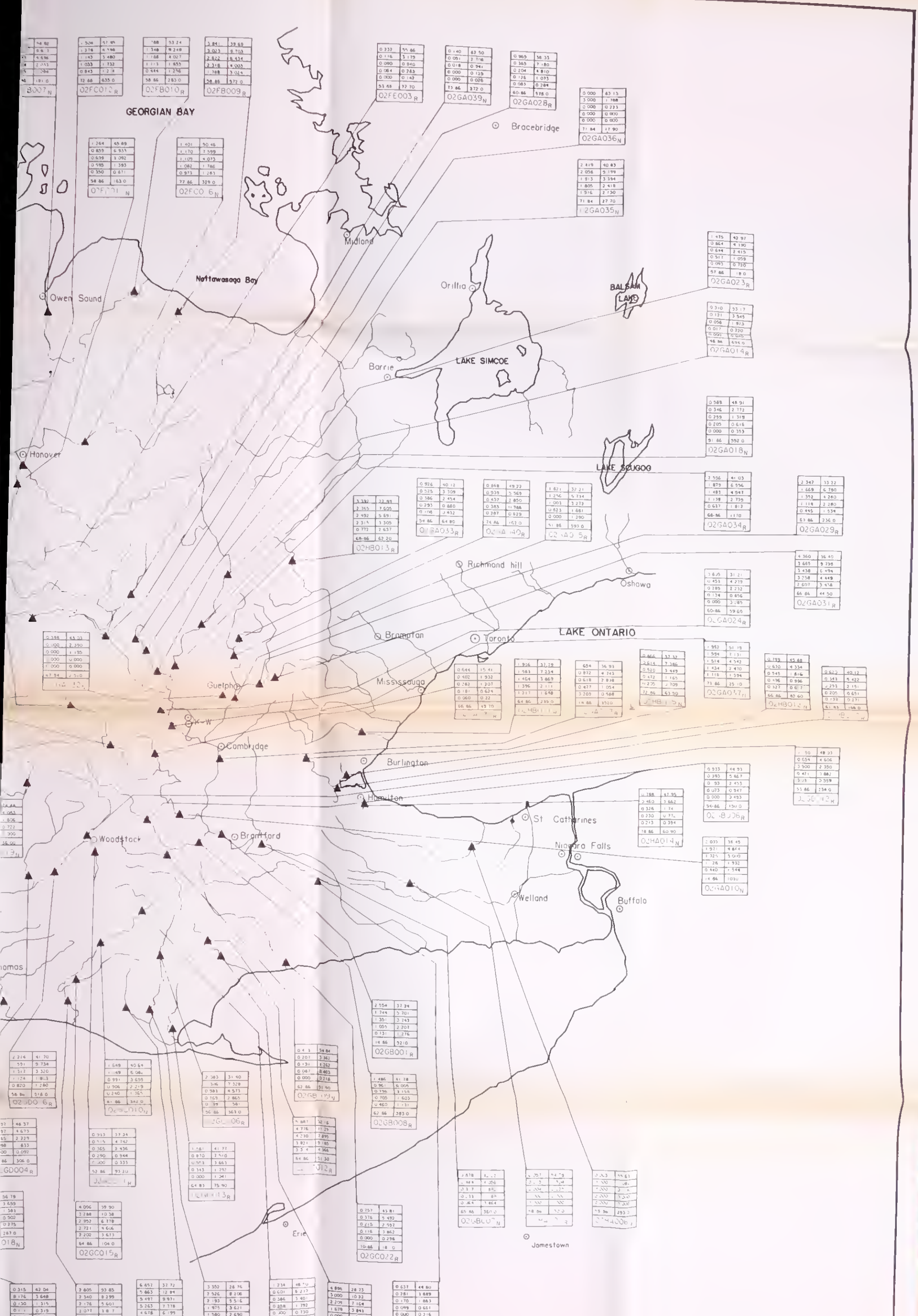

UNIT LOW FLOW CHARACTERISTICS
OF STREAMS IN
SOUTHWESTERN AND WEST CENTRAL ONTARIO

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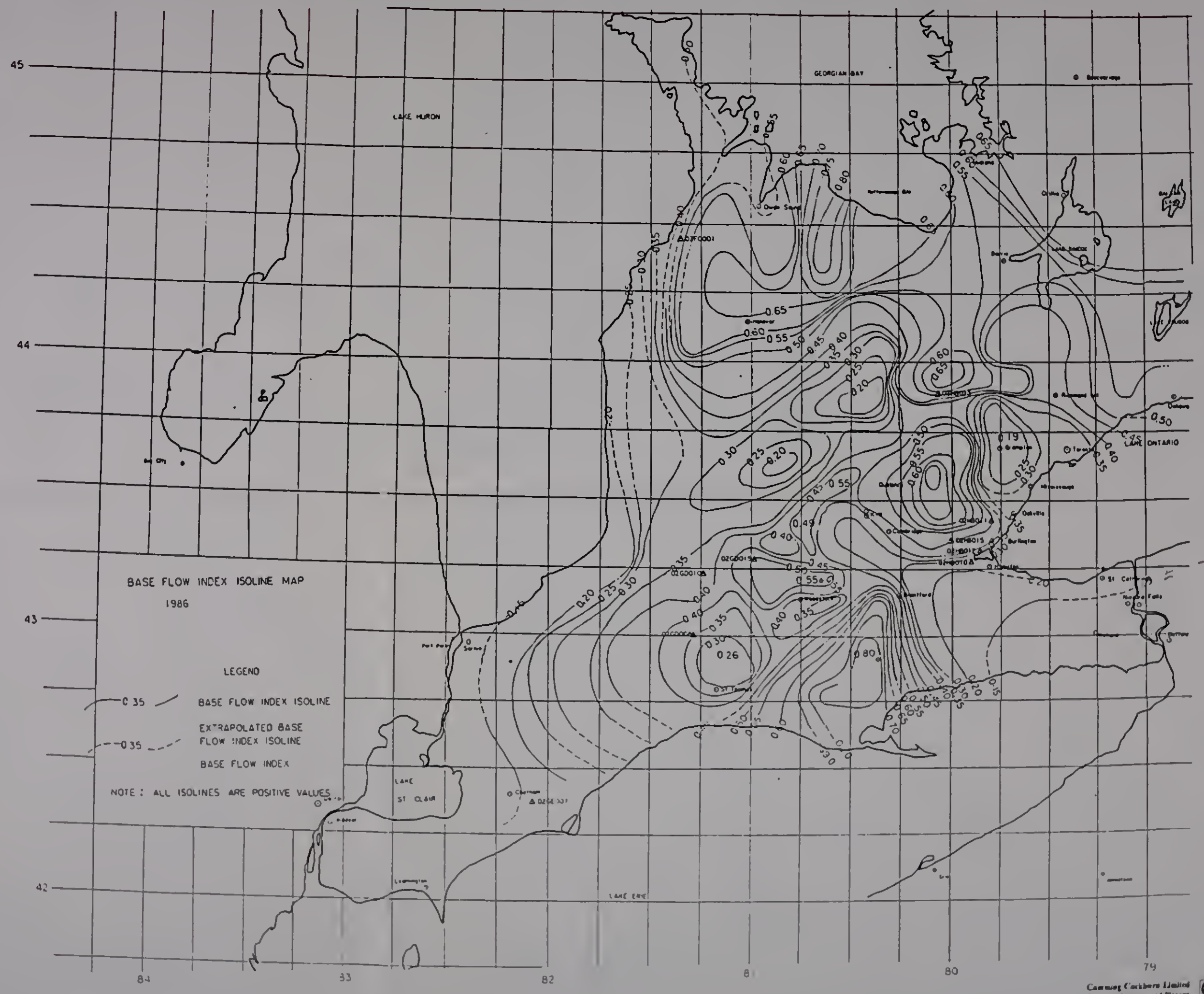

BASE FLOW INDEX ISOLINE MAP

1986

LEGEND

0.35 BASE FLOW INDEX ISOLINE

0.35 EXTRAPOLATED BASE FLOW INDEX ISOLINE

BASE FLOW INDEX

NOTE : ALL ISOLINES ARE POSITIVE VALUES

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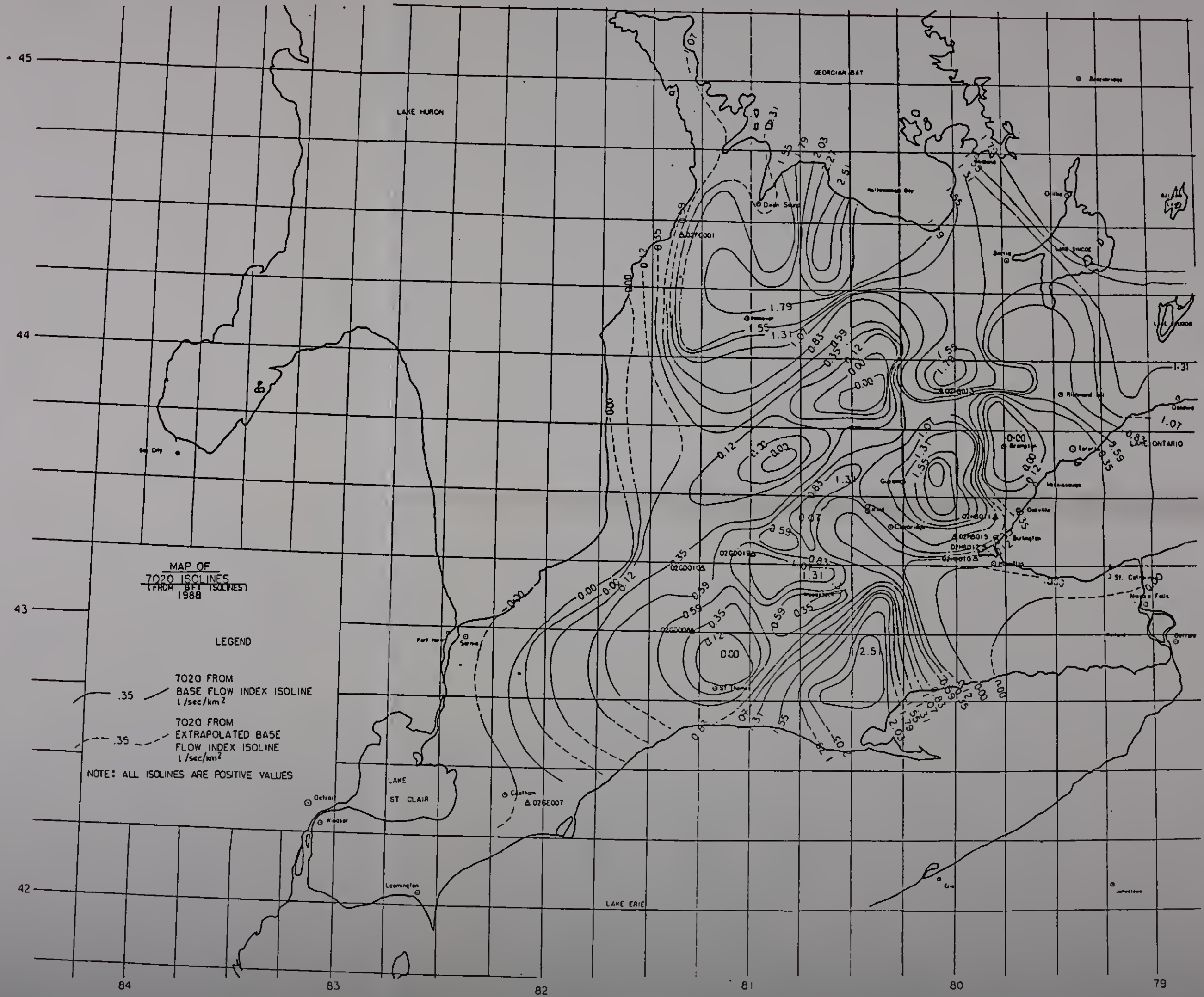
FIGURE 3 6

7Q10	75%DUR
7Q20	95%DUR
MIN DAY	99%DUR
PERIOD	AREA
STATION # RC	

PERIOD	PERIOD OF RECORD (years)
AREA	DRAINAGE AREA (km^2)
MIN DAY	LOWEST 1 DAY AVERAGE FLOW (m^3/s)
STATION #	WSC STATION IDENTIFICATION
RC	REGULATION CODE

02FA001	SAUBLE RIVER AT SAUBLE FALLS
02FA002	STOKES RIVER NEAR FERNDALE
02FB007	SYDENHAM RIVER NEAR OWEN SOUND
02FB009	BEAVER RIVER NEAR CLARKSBURG
02FB010	BIGHEAD RIVER NEAR MEAFORD
02FC001	SAUGEEN RIVER NEAR PORT ELGIN
02FC002	SAUGEEN RIVER NEAR WALKERTON
02FC011	CARRICK CREEK NEAR CARLSRUHE
02FC012	SOUTH SAUGEEN RIVER NEAR HANOVER
02FC013	NORTH SAUGEEN RIVER NEAR PAISLEY
02FC015	TEESWATER RIVER NEAR PAISLEY
02FC016	SAUGEEN RIVER ABOVE DURHAM
02FD001	PINE RIVER AT LURGAN
02FE002	MAITLAND RIVER BELOW WINGHAM
02FE003	MIDDLE MAITLAND RIVER NEAR LISTOWEL
02FE004	MAITLAND RIVER NEAR DONNYBROOK
02FE005	MAITLAND RIVER ABOVE WINGHAM
02FE007	LITTLE MAITLAND RIVER AT BLUEVALE
02FE008	MIDDLE MAITLAND RIVER NEAR BELGRAVE
02FE009	SOUTH MAITLAND RIVER AT SUMMERHILL
02FF002	AUSABLE RIVER NEAR SPRINGBANK
02FF007	BAYFIELD RIVER NEAR VARNA
02FF008	PARKHILL CREEK ABOVE PARKHILL RESERVOIR
02GA003	GRAND RIVER AT GALT
02GA010	NITH RIVER NEAR CANNING
02GA014	GRAND RIVER NEAR MARSVILLE
02GA015	SPEED RIVER BELOW GUELPH
02GA016	GRAND RIVER BELOW SHAND DAM
02GA018	NITH RIVER AT NEW HAMBURG



MAP OF
7Q20 ISOLINES
(FROM BFI ISOLINES)
1988

LEGEND

.35 — 7Q20 FROM BASE FLOW INDEX ISOLINE l/sec/km²

.35 - - - 7Q20 FROM EXTRAPOLATED BASE FLOW INDEX ISOLINE l/sec/km²

NOTE: ALL ISOLINES ARE POSITIVE VALUES

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FIGURE 4.8

UNIT LOW FLOW CHARACTERISTICS OF STREAMS IN SOUTHWESTERN AND WEST CENTRAL ONTARIO

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